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Productivity Benefits and Cost Efficiencies from ITS Applications to Public Transit: The Evaluation of AVL

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CALIFORNIA PATH PROGRAM  
INSTITUTE OF TRANSPORTATION STUDIES  
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## **Productivity Benefits and Cost Efficiencies from ITS Applications to Public Transit: The Evaluation of AVL**

**David Gillen, Elva Chang, Doug Johnson**

**California PATH Working Paper  
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Report for MOU 3001

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MOU 3001- EVALUATION METHODS FOR MEASURING THE VALUE OF ITS SERVICES AND BENEFITS FROM IMPLEMENTATION

**Productivity Benefits and Cost Efficiencies from ITS Applications to Public Transit: The Evaluation of AVL**

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Deliverable under MOU 3001 June 2000

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## 0 EXECUTIVE SUMMARY

California's Transportation Plan [CTP] was designed to set the course for the future of transportation in California. The three guiding goals of this plan are to promote the economic vitality of California by assuring mobility and access for people, goods, services and information, provide safe, convenient and reliable transportation and, provide environmental protection and energy efficiency. In order to realize this vision Caltrans has invested in the Advanced Transportation Systems Program [ATS]. The objective of the program is to accelerate implementation of advanced transportation technology applications. A sub-component of ATS is the Intelligent Transportation Systems (ITS), which was the designation given to the multimodal package of transportation innovations.

Investments in ITS programs will generate different types, magnitudes and longevity of payoffs. The variability of both benefits and costs will create a degree of uncertainty regarding the evaluation of projects as well concern as to accurate values for benefits and costs. These features create an important challenge since public/private partnerships, private initiatives and public investment will address California's transportation needs in the years to come. In each case the investment dollars will be available through public capital markets *only if it can be shown* that these projects will meet California's transportation needs. Up until recently the 'promise' of net positive benefits from implementing ITS projects carried the weight of opinion that continued support was desirable. We now have a number of implementation sites as well as sophisticated simulation models that provide the data for such an evaluation.

MOU 3001 is a continuation of MOU 357, which provided a framework to undertake the evaluation of ITS projects. What distinguishes MOU 3001 is that not only are individual technologies evaluated as an after-the-fact implementation of ITS, but the process of the application is also evaluated. These applications will be conducted after achieving a greater understanding of the productivity benefits of ITS and the existence and option value benefits of ITS respectively. The project also examines the synergies of multiple ITS application to explore the potential for 'network' effects.

Currently, many applications of ITS to the California's highway and transit systems focus upon the real resource savings that can be generated such as time, fuel and operating cost savings. *Productivity* is conventionally measured by the amount of output per unit input for things we are doing today. The research reported in this document uses Total Factor Productivity (TFP) techniques, with which we develop measures of productivity performance of public transit systems of varying size and location, and use this baseline to examine the potential contribution of alternative ITS applications. TFP aggregates outputs on the basis of their revenue contribution and inputs on the basis of their relative importance to total costs to calculate the overall firm productivity as a function of these quantities.

The focus of this research was how the opportunities for improving efficiency via AVL are manifest in the transit operation, if at all, through the use of TFP. It is important to keep in mind that AVL is an enabling technology that provides *an opportunity* for the transit agency to develop strategies that can reduce costs and improve productivity through better use of resources as well as perhaps using less of them. AVL represents the application of an evolving high technology in which transit operations and control strategies are introduced by integrating information on vehicle performance and location. The evaluation of the potential impacts of AVL must consider how AVL affects these strategies and operations.

At the present time, four prime objectives for the introduction of AVL have been identified by transit agencies in the U.S. They are: improved schedule adherence and timed transfers, more accessible passenger information, increased availability of data for transit management and planning, and the efficiency/productivity improvements in transit services. These objectives can be met with AVL since it increases the firm's capability to monitor information on vehicle position and operational status. By utilizing AVL, firms can increase fleet utilization and reduce input factors such as fuel, labor and capital. Revenue planning and efficiency can be improved through the use of on-board electronic fare collection. This can also provide for seamless transfers by implementing/supporting a common or universal fare medium (e.g. a fare card that is accepted by all operators in a defined region).

Firms were considered for selection based on their use of AVL, their comparability with an AVL agency and the availability of useful data for the agency. Our final list contained twenty-three agencies, with data for each agency covering the years 1988-1997. Data for each agency was collected from the Federal Transit Authority's Section 15 Reports (later known as the National Transit Database) which contain both operation and financial information for the agencies included.

The results from the study are very insightful. AVL was found to be an important factor in both system performance and cost savings. The introduction of AVL had a positive and significant impact on transit firm productivity. Also, the positive productivity affect is larger when output is measured by Passenger Miles than when it is measured by Vehicle Revenue Miles. In fact the value of the coefficient is almost double. Improving productivity and developing better service information can be obtained through the use of AVL.

The use of AVL also leads to increased passenger trips by a non-trivial amount. Unfortunately, due to limited information, it is not possible to explore further as to how the increase in passenger trips is accomplished. Nonetheless, AVL does have a positive benefit on the number of passenger trips.

In the bus fleet regression, AVL has a negative coefficient indicating the use of AVL by the transit firm will result in fewer buses being used, given the number of vehicle miles

and the number of passenger trips. Similarly, we found the cost per vehicle mile was lower when the transit firm used AVL. In addition to these cost savings, our research indicates that given fleet size and usage, AVL will reduce the annual maintenance hours for a given agency. These results have strong implications in a time when agencies are pushed to cut costs and maintain consistent levels of services.

While the information regarding the use of AVL has been insightful, little information could be gathered regarding the benefits from different types of AVL. In our study of the measures of TFP, there was no case in which a particular AVL technology was statistically significant. Therefore, the relative cost of comparable AVL systems should be the main consideration for firms which install AVL systems in the years to come.

Overall, the results of this research indicate a number of efficiency gains resulting from the use of AVL systems. As transit agencies across the country strive to offer the best service possible, the use of ITS and specifically AVL will be of the utmost importance. Since the number of agencies using AVL has increased greatly in the last few years, there will be excellent opportunities to revisit this topic in the years to come.

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## 1 INTRODUCTION

California's Transportation Plan [CTP] was designed to set the course for the future of transportation in California.<sup>1</sup> Three comprehensive policies form the fundamental structure of the plan; promoting the economic vitality of California by assuring mobility and access for people, goods, services and information, provide safe, convenient and reliable transportation and, provide environmental protection and energy efficiency. The Caltrans Strategic Plan in keeping with the CTP creates a vision of a balanced, integrated multimodal transportation network to move people, goods, services and information freely, safely and economically. In order to realize this vision Caltrans has invested in the Advanced Transportation Systems Program [ATS], a multimodal research and development program. This program provides a foundation for the application of advanced technologies to transportation in California. The objective of the program was and is to accelerate implementation of advanced transportation technology applications. A sub-component of ATS is the Intelligent Transportation Systems (ITS), which was the designation given to the multimodal package of transportation innovations. Its is, however, more narrowly designated for the use of advanced technologies in electronics and information to improve the performance of vehicles, highways and transit systems.

Among the various categories of ITS applications will be projects dealing with traveler information systems, traffic management systems, vehicle safety systems, public transportation systems and commercial vehicle operations to name a few. In some cases these projects will require significant capital investments and continuing operations and management expenses, while other projects will represent small capital investments. Some projects will be broadly based in urban areas while others may be specific to a link at a given location such as electronic tolling. The projects will vary in a number of dimensions from size, capital intensity, geographic coverage and user groups effected. The variety and coverage creates a challenge for investment analysis.

Investments in infrastructure and management strategies under the ITS program will generate different types, magnitudes and longevity of payoffs. They will have different levels of costs and both costs and benefits will have risks of varying size. The variability of both benefits and costs will create a degree of uncertainty regarding the evaluation of projects as well concern as to accurate values for benefits and costs. These features create an important challenge since public/private partnerships, private initiatives and public investment will address California's transportation needs in the years to come. In each case the investment dollars will be available through public capital markets only if it can be shown that these projects will meet California's transportation needs now and into the future in an efficient or cost effective way. If these projects do not meet financial and economic tests in a transparent manner, including a compensation for greater risk and uncertainty, the private sector is unlikely to undertake the development of new ATS products in the future. This does not mean all projects must generate at least a market rate

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<sup>1</sup> See, California Department of Transportation, New technology and Research Program *Advanced Transportation Systems Program Plan: 1996 Update*, December 1996



of return; indeed there may be some argument for subsidy. What it does mean is that significant policy issues can only be addressed if the benefits, cost and risks can be identified for each project. Indeed, the quality of decisions will be threatened by the lack of or failure to use aids that help guide the public use of scarce resources.

Up until recently the 'promise' of net positive benefits from implementing ITS projects carried the weight of opinion that continued support was desirable. However, there has been near a decade of R&D into ITS technologies and various test-beds have been studied. Advocates are being pressed by practitioners and policy makers and those having to deal with tightening budgets and growing congestion to provide clear evidence that ITS will deliver what it has promised. We now have a number of implementation sites as well as sophisticated simulation models that provide the data for such an evaluation.

MOU 3001 is a continuation of MOU 357. That research provided a preliminary framework to undertake the evaluation of the implementation of ITS projects. What distinguishes MOU 3001 from others is that not only are individual technologies evaluated as an after-the-fact implementation of ITS, but the process of the application is also evaluated. An ITS project application is necessarily a partnership between Caltrans headquarters and some other agency or agencies. These might be one of the Caltrans districts, a transit agency, a local government (e.g. MTC) or a Federal agency. One needs to ask, how has ITS enabled the agencies to partner and provide an integrated systems solution as distinct from an agency solution? And how has the way in which ITS implementation been carried out effected the benefits and costs? If we can understand the process of implementation, the learning curve effect, our ability to both realize benefits and realize them sooner will be enhanced.

MOU 3001 undertakes specific evaluations in two different areas of ITS application: (1) public transportation operations with specific consideration of AVL applications and (2) freeway service patrol and emergency management. These applications will be conducted after achieving a greater understanding of the productivity benefits of ITS and the existence and option value benefits of ITS respectively. The project also examines the synergies of multiple ITS application to explore the potential for 'network' effects.

Understanding better these two categories of benefits is motivated by examining the 'mission' of ITS which is to improve the productivity of the current system and to improve the quality of life of the community through improvements in accessibility and mobility. Currently, many applications of ITS to the California's highway and transit systems focus upon the real resource savings that can be generated such as time, fuel and operating cost savings. *Productivity* is conventionally measured by the amount of output per unit input for things we are doing today. The research reported in this document uses Total Factor Productivity (TFP) techniques, with which we develop measures of productivity performance of public transit systems of varying size and location, and use this baseline to examine the potential contribution of alternative ITS applications.

## 1.1 Background

In a well functioning market, if transportation services are provided under constant returns to scale and competition among modes dissipates all rents, the entire benefit of any transportation investment can be measured by the net welfare (aggregate of consumer and producer surplus) gain under the transportation demand curve.<sup>2</sup> This would be the measure calculated in a conventional benefit-cost application. However, we have sufficient evidence that transit does not exhibit constant returns and we know markets are less than perfect (in many cases due to government failure to price efficiently). Hence, certain benefits may not be fully capitalized into the demand curve. In particular, some gains in public-transport production may go unaccounted for. The application of Automatic vehicle Location (AVL) technology is just such a potential source of benefit.

AVL represents the application of an evolving high technology in which transit operations and control strategies are introduced through integrating information on vehicle performance and location. The evaluation of the potential impacts of AVL must consider how AVL affects these strategies and operations. The evaluation of the potential impacts *with* and *without* AVL provides important input for the agency to select the most promising strategy for further detailed study and implementation. The natural extension to this evaluation process is the identification of the benefits/impacts of alternative control strategies utilizing AVL. In addition we can explore the implementation of AVL across several transit agencies to assess network synergies from operations but also from implementation.<sup>3</sup>

At the present time, four prime objectives for the introduction of AVL have been identified by transit agencies in the U.S. They are: improved schedule adherence and timed transfers, more accessible passenger information, increased availability of data for transit management and planning, and the efficiency/productivity improvements in transit services. These objectives can be met with AVL since it increases the firm's capability to monitor information on vehicle position and operational status. By utilizing AVL, firms can increase fleet utilization and reduce input factors such as fuel, labor and capital. Revenue planning and efficiency can be improved through the use of on-board electronic fare collection. This can also provide for seamless transfers by implementing/supporting a common or universal fare medium (e.g. a fare card that is accepted by all operators in a defined region). All of this means that productivity will (should) be higher and costs lower for those agencies using AVL systems.

In this study we use information from the operations and financial information to explore whether and how AVL applications lead to changes in productivity and resource use. We use information from the Federal Transit Commission's database augmented with information on AVL applications. The data set is unique since it captures the impact of AVL within a firm and across firms as well as over technologies. Section 3 of this report

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<sup>2</sup> Mohring and Harwitz (1962) made this point nearly 40 years ago.

<sup>3</sup> Having established a knowledge base for local transit agencies may be critically important to the success of implementation or even the decision to undertake an ITS implementation at all.

provides a survey of the received wisdom of AVL applications and the empirical work that has been completed. In section 4 we review the literature on productivity and provide arguments why this can be used to investigate the contribution of AVL to an agencies efficiency. Section 5 contains a description of the data and section 6 reports the results of the empirical assessment of applications of AVL. The final section contains a summary and conclusions.

## 2 ITS APPLICATIONS IN PUBLIC TRANSPORTATION

The importance of technology to the future of public transportation cannot be overstated. As transit agencies are pushed to produce greater ridership and hours of services while keeping costs down, technological advancements will help agencies be as efficient as possible with their resources. The immense size of many agencies (both Seattle and Baltimore's transit agencies have over 800 vehicles) presses the need for greater automation to more closely monitor services and ridership. And the number of vehicles is not the only issue relating to agency size. Many agencies have enormous networks which may cover hundreds of miles throughout a region. In such a large system, precise information may have a large impact on agency operations.

The Federal Transit Authority (FTA) has cited technological advancement as a cornerstone of transit systems in the new century.

'FTA will support deployment of technological innovation to improve personal mobility, minimize fuel consumption and air pollution, increase ridership, and enhance the quality of life of all communities.'<sup>4</sup>

As transit services strive for greater responsiveness in their services, the flexibility and information supplied by different technological advancements may make a huge difference in the years to come.

Many of the technologies implemented by transit agencies can be considered part of a larger system called Automated Vehicle Monitoring (AVM). These technologies improve emergency location of vehicles, vehicle performance monitoring and service control, data collection, passenger information communication including compliance with the Americans with Disabilities Act, fare collection and traffic signal priority<sup>5</sup>. Implementation of AVM systems, either piecemeal or as a complete system, is a complicated process that can take years to operate smoothly.

Details of the value and contribution of AVL systems to productivity improvements, cost reductions, service delivery of fixed-route transit and ADA-type paratransit services,

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<sup>4</sup> FTA website, <http://www.fta.dot.gov/research/index.htm>

<sup>5</sup> Transit Cooperative Research Program, "TCRP Synthesis 24, AVL Systems for Bus Transit", Transportation Research Board National Research Council

ridership and revenue are needed before investment decisions in AVL can be made. This includes decisions on: whether to invest in AVL; which type of AVL technology to select; what level of investment to choose and the timing of any such investments and, benefits/impacts of alternative control strategies utilizing AVL.

There are a number of different ways in which AVL and other technologies can improve transit performance. In the "Advanced Public Transportation Systems: The State of the Art Update 1996", four ways in which technology can affect transit are cited.<sup>6</sup> They are:

**Fleet Management:** Effective vehicle and fleet planning, scheduling, and operations. Fleet Management focuses on the vehicle, improving the efficiency and effectiveness of the service provided (the "supply side"), and on passenger safety. By making transit more efficient and reliable, it should be more attractive to prospective riders, and the municipalities they serve.

**Traveler Information:** Facilitate decision making before a passenger's trip and during the trip (en-route). Information can be provided to trip makers at home, work, transportation centers, wayside stops, and on-board vehicles. With links to automatic vehicle location, traveler information systems specifically for transit are beginning to provide real-time information, such as arrival times, departure times, and delays.

**Electronic Fare Payment:** A variety of benefits are anticipated from EFP. They are: more sophisticated fare pricing systems, based on distance traveled, time of day, and user profile (e.g., school children, elderly, frequent users); elimination of cash and coin handling to improve security, reduce dwell time and lower costs; automation of the accounting and financial settlement process, which will also reduce costs; creation of multimodal and multi-provider transportation networks that are seamless for the rider but operationally and organizationally sound for the multiple modes and providers.

**Transportation Demand Management Technologies:** The goal of these technologies is to maximize the ability of the current transportation network - roads and transit - to serve the recent rapid increase in demand for transportation. This is accomplished through a combination of, among other things, coordination of transportation service providers, and enhanced incident response and monitoring.

## 2.1 AVL Technology: A Description and Experience

Advanced Vehicle Location (AVL) systems, in their most basic form, help track the whereabouts of vehicles on a network. AVL is considered part of the fleet management technologies, which concentrate on improving vehicle operations, future planning efforts and safety. By knowing the exact (though this varies across different AVL technologies)

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<sup>6</sup> Robert Casey, Lawrence Labell, Ross Holmstrom, Joseph LoVecchio, Carol Schweigaer and Terrence Sheehan from Volpe Transportation Systems Center and EG&G Dynatrend Inc., "Advanced Public Transportation Systems: The State of the Art Update 1996", January 1996  
<http://www.fta.dot.gov/library/technology/APTS/update/index.html#TOC>

location of vehicles on a transit network, the agency has clear, objective information regarding those vehicles. Historically, dispatchers would need to verbally confirm the position of buses spread across a city. As AVL systems are implemented, vehicle information is automated and available for both current operations and planning purposes.

AVL systems have been in use for 30 years. Starting in 1969, transit agencies in the U.S. of all sizes and regions, experimented with various AVL systems<sup>7</sup>. There are four basic technologies employed for AVL systems<sup>8</sup>. In some cases, two technologies are used to create redundancy in the system. The most common technologies are:

- Signpost and odometer
- Radio navigation/location
- Dead-reckoning
- Global Positioning System (GPS Satellite Location)

The signpost/odometer system has been the most common until recently. In this system, a receiver is mounted on the bus, while transmitters are placed along the bus' route. Utility poles and signposts are most commonly used as mounting locations for these transmitters. The bus picks up a low-powered signal from these transmitters as it passes by, and the mileage noted. When the bus reports its location, the distance from the last pole is used to locate the vehicle's position on a route. The system can be run in reverse, with the transmitter on the bus and multiple receivers mounted along the route. However, should the bus need to leave the route, there will be no information about the bus, so most agencies prefer to have a receiver on the bus. This older technology has some drawbacks. Creation of new routes requires the placement of new transmitters, and the system is maintenance intensive due to the relatively high number of transmitters and receivers involved.

Radio-location systems use a low-frequency signal to cover the system, and the buses are located as they receive the signal. Loran-C (Long Range Aid to Navigation) is the most common type of land based radio location. Despite the simplicity of the system, it is subject to some major drawbacks. Overhead power lines or power substations can cause signal interference, and signal reception is typically very poor in canyons.

Dead reckoning is among the oldest navigation technologies. Dead reckoning sensors can measure distance and direction from a fixed point (under the most basic setup, an odometer and compass could be used to calculate position from a specific stop on a route). Typically, these systems act as a backup to another AVL system. This relatively inexpensive system is self-contained on the bus. This system has a number of drawbacks. Uneven surfaces and hills can compromise the positioning information. Should the vehicle leave a fixed route, its location will no longer be known since there will be no

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<sup>7</sup> "AVL Systems for Bus Transit"

<sup>8</sup> "Advanced Public Transportation Systems: The State of the Art Update 1996" pg. 6

waypoints off the fixed route. Also, accuracy degrades with distance traveled, and regular recalibration is required (tire circumference changes with wear)<sup>9</sup>.

Due to the shortcomings of the other AVL technologies, GPS became the most popular system for new installations over the last few years. GPS utilizes the signals emitted from a network of 24 satellites, which are picked up by a receiver placed onboard the bus. The satellite system covers almost all of North America, eliminating the need to place transmitters/receivers along any route. The existence of the satellite system means that the main cost for the agencies result from purchase of the GPS receivers and equipment to transmit to dispatch. While the U.S. military, which oversees the satellite system, has limited the accuracy of the system in the past, it is now allowing more accurate readings. The accuracy and reasonable cost of GPS makes it the most appealing, though it too has some problems. Foliage, tall buildings, and tunnels can temporarily block the satellite signal, and at times satellite signals do not reach specific locations. Typically dead reckoning is used in conjunction with GPS to fill in such gaps.

The final issue regarding the technology concerns the relay of the buses' positions to a central dispatcher. A central computer communicates with each bus and exchanges the information automatically over radio waves. There are two different methods for collecting this information, *polling* and *exception reporting*. Under polling, the central computer contacts each bus on the network in turn. When it has reached the 'last' bus, it will start over from the beginning. This process can take a few seconds or many minutes, depending on the number of buses and the capabilities of the computers. With exception reporting, the buses send in their signal only at a few specific locations, or if they have fallen far off of their schedule. Under exception reporting, dispatch not only knows the position of the bus, but also the scheduled position of the bus. This extra amount of information makes exception reporting more useful, though somewhat more expensive<sup>10</sup>.

This information is then typically sent to a pair of personal computers (PCs) at the dispatch office. One computer serves as the communication machine, making contact with the buses. The second PC will usually map the vehicles' location on the network. It is important to realize that proper use of mapping software like a geographic information system (G.I.S.) or computer aided design (CAD) is required in order to display this information effectively. This is a concern for many agencies with limited technology resources at their disposal. Many agencies have neither the money for additional equipment, nor for the trained personnel required. Training of employees is a key to maximizing the use of an AVL system. These PCs help anticipate and address bus failures, monitor schedule adherence and emergency response, and they can trigger location specific audio and visual announcements to comply with the Americans with disabilities act (ADA)<sup>11</sup>.

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<sup>9</sup> "TCRP Synthesis 24, AVL Systems for Bus Transit", pg. 17

<sup>10</sup> "Advanced Public Transportation Systems: The State of the Art Update 1996" pg. 23

<sup>11</sup> *ibid*, pg. 8

There are numerous anticipated benefits resulting from the use of AVL<sup>12</sup>. These benefits include:

- Increased dispatching and operating efficiency
- More reliable service (on-time performance, leading to increased ridership)
- Quicker response to service disruptions
- Information to be used in passenger information systems
- Increased driver and passenger safety and security (silent alarms with precise location information)
- More effective response to mechanical failures, reducing maintenance costs
- Inputs to traffic signals for signal preemption use
- Improved data (quantity and quality) automatically collected for agencies at a lower cost

So far, most agencies have not quantified the benefits resulting from AVL. The fact that AVL systems are able to make improvements throughout an agency (operations, maintenance, administration) makes the use of common measures of effectiveness (MOE) inadequate. Studies of just safety or revenue hours may not reflect all the benefits accruing to an agency. However, agencies have reported more ‘anecdotal’ benefits such as more flexible assignments, quicker emergency response, improved on-time monitoring, and a better capability to handle grievances<sup>13</sup>. While these benefits may be hard to quantify for the agencies, they do reflect the general importance of an AVL system to almost any transit agency.

It is important to consider how transit agencies' performance is reviewed. Since there is so much variety among transit agencies (size, population, cost structures, etc), it is very difficult to compare agencies to one another. Agencies need a set of quantitative indicators capable of tracking performance in sufficient detail in order to identify the real sources of gain (or loss) in overall productivity<sup>14</sup>.

## **2.2 Measuring Productivity and Cost Efficiency**

The range of affects of AVL can be classified into either demand side or supply side. On the demand side (an issue we do not examine in this paper but is part of the research project) AVL provides the transit firm with an opportunity to increase the information on vehicle location vis a vis particular stops and expected arrival times. This allows customers to better plan their time and increases the value of using transit.

AVL in conjunction with fare collection information (number of people boarding at given times and paying given fares) can provide the transit agency with data to design fare

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<sup>12</sup> *ibid*, pg. 5

<sup>13</sup> “TCRP Synthesis 24, AVL Systems for Bus Transit”, pg. 3

<sup>14</sup> Hensher, David, "Editorial for Transportation Research Part B", Transportation Research Part B, vol. 26B, no. 6, 1992, pg. 433

structures that meet particular objectives and to plan the use of their capacity and better tailor it to fit demand.

The focus of this research was how the opportunities for improving efficiency via AVL are manifest in the transit operation, if at all. It is important to keep in mind that AVL is an enabling technology that provides a chance for the transit agency to develop strategies that can reduce costs and improve productivity through better use of resources as well as perhaps using less of them. In exploring this impact we utilize a measure of productivity, TFP, that has a rich history in the transportation economics literature but has heretofore not been used to investigate the impact of technological change` such as that represented by the introduction of ITS.

### 2.2.1 TOTAL FACTOR PRODUCTIVITY (TFP)

Productivity measurement has generally been implemented using partial productivity measures. These include popular indexes such as output per worker, or per hour of labor. Others that have been used is output per machine hour or per machine. The obvious problem with these measures are they do not take account of the contribution of the nature, type (vintage) and extent of the other factors that can clearly contribute to the productivity of the factor input that is being considered. As a means of correcting this shortcoming economists have developed an index which considers all factors simultaneously and all outputs. The index, termed total factor productivity or TFP, aggregates outputs on the basis of their revenue contribution and inputs on the basis of their relative importance to total costs.

The initial TFP measure was constructed as:

$$\ln\left(\frac{TFP_k}{TFP_l}\right) = \sum_i \left(\frac{R_{ik} + R_{il}}{2}\right) \ln\left(\frac{Y_{ik}}{Y_{il}}\right) - \sum_i \left(\frac{S_{ik} + S_{il}}{2}\right) \ln\left(\frac{X_{ik}}{X_{il}}\right)$$

where k and l are adjacent time periods, the Y's are the output indices and the X's the input indices. R's are the revenue shares and the S's are the cost shares. This measure of TFP has been shown to be an exact index procedure that corresponds to a homogenous translog production function which contains no implicit restrictions of separability or neutral technological change.

The measure of TFP illustrated above can be used to make time series and cross-sectional comparisons of TFP. In cross sectional comparisons indices k and l are interpreted as different firms rather than different time periods. A problem does arise if we have a panel of data in which the data are both time series and cross sectional. This requires the development of a *multilateral TFP index* that allows bilateral comparisons across firms and over time. This index is constructed as:



$$\begin{aligned} \ln\left(\frac{TFP_k}{TFP_l}\right) &= \frac{1}{2} \sum_i (R_i^k + \bar{R}_i) \bullet (\ln Y_i^k - \ln \bar{Y}_i) - \frac{1}{2} \sum_i (R_i^l + \bar{R}_i) \bullet (\ln Y_i^l - \ln \bar{Y}_i) \\ &- \frac{1}{2} \sum_i (S_n^k + \bar{S}_n) \bullet (\ln X_n^k - \ln \bar{X}_n) + \frac{1}{2} \sum_i (S_n^l + \bar{S}_n) \bullet (\ln X_n^l - \ln \bar{X}_n) \end{aligned}$$

where  $\bar{R}$  is the revenue share averaged over all firms and time periods and similarly for S on the input side. All bilateral comparisons are base-firm and base year invariant.

This equation can be derived from a translog transformation structure by taking the difference between each firm's transformation function and the function resulting from arithmetic averaging of the transformation function across all observations.

A measure of TFP can provide a single index for use in comparisons across time, multiple agencies, and even for comparison with private enterprises. TFP measures total output produced per unit input<sup>15</sup>. The concept call for the aggregation of input data (fleet size, operating costs, labor hours, etc) to try and examine the source of improved efficiency for an agency. Since there are many important output measurements to be considered (both quantity of service supplied and consumed as well as the quality of that service), TFP makes it possible to evaluate for all of these. The acceptance of TFP is reflected in its increasing use for recent research purposes. TFP has been used to study transit systems for fifteen years.

## 2.2.2 STUDIES OF TRANSIT USING TFP

Kim (1985) studied the Israeli intercity bus services using a cost efficiency measure, similar to TFP. Using input costs and revenues, he found that average cost had dropped for all but one year of the study<sup>16</sup>. Obeng et. al. (1986) also used TFP to study a set of 20 transit systems in the U.S. Agency information from 1956 to 1981 was compiled and examined. Vehicle miles and passenger trips were used to study the output of the system in this case. No significant productivity growth was observed over the study period<sup>17</sup>. In 1990, a follow up study to Obeng's 1986 study was completed. Here, the 25 largest U.S. transit agencies were examined from 1955-1982. The report suggested that productivity was largely stable for these agencies. However, when examining passenger miles, both fleet size and area population were meaningful variables. This suggests that transit agencies should make an effort to improve their service on congested corridors with careful use of their fleet and manpower<sup>18</sup>.

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<sup>15</sup> *ibid*, pg. 434

<sup>16</sup> Kim, Moshe, "Total Factor Productivity in Bus Transport", *Journal of Transport Economics and Policy*, vol. 19, no. 2, May 1985, pg. 173-182.

<sup>17</sup> Obeng, Kofi and Benjamin, Julian and Addus, Abdullalam, "An Initial Analysis of Total Factor Productivity for Public Transit", *Transportation Research Record 1078*, Transportation Research Board, Washington D.C., 1986, pg. 48-55

<sup>18</sup> Benjamin, Julian and Obeng, Kofi, "The Effect of Policy and Background Variables on Total Factor Productivity for Public Transit", *Transportation Research Part B*, vol. 24, no. 1, 1990, pg. 1-14

Obeng et al. (1992) again examined TFP growth for transit agencies from 1983-1988. 23 agencies providing motorbus only service with at least 25 vehicles were reviewed. An average value of 1.1% growth occurred, and only one agency showed a decreasing TFP factor over the whole period. This growth in TFP suggests increased overall efficiency for these agencies<sup>19</sup>.

Academic research into AVL benefits only began recently. Chira-Travala et al. (1997) studied the use of AVL on Santa Clara's paratransit system, Outreach Inc. AVL was gradually introduced between 1995 and 1996, but data was reviewed beginning in 1993 through 1996. This study observed a significant drop in the unit cost (per passenger mile). Vendor payment dropped 7-14%, though no conclusive information on passenger travel time or deadheading was found. The report attributed much of these savings to the new AVL system<sup>20</sup>.

The other study of interest came from Nakanishi and Martinez (1998). They used data envelopment analysis (DEA) to try and track the impact of AVL installed on a portion of five agencies' rail fleets. More than 20 variables were used to try and isolate the impact of AVL, however the analysis found no clear evidence that AVL had improved system performance<sup>21</sup>.

### 3 MODELING METHODOLOGY DG

Our research investigates three issues. First, does the introduction of AVL by a transit firm have an impact on firm efficiency, as measured by TFP. Secondly, does it matter which type of AVL is used, that is does GPS have a greater impact than signpost technology? Third, if efficiency is impacted by AVL where does it show up in the firm cost behavior?

#### 3.1 Measuring the impact of AVL

The first two issues are to be investigated using a calculation of TFP and a subsequent regression of TFP on a set of explanatory variables that would allow us to identify the separate contribution of AVL to the TFP measure. The calculated measure of TFP is a 'gross' measure of productivity since it looks simply at the growth in outputs over the growth in inputs. It may be possible to examine the TFP measure for a firm or point in time when AVL was introduced and the change in TFP could be attributed to the introduction of AVL. This may result in an overestimate of the contribution of AVL to firm productivity growth and secondly, it would not be possible to distinguish different

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<sup>19</sup> Obeng, Kofi, and Assar, Nasir, and Benjamin, Julian, "Total Factor Productivity for Public Transit", *Transportation Research Part A*, vol. 26, no. 6, 1992, pg. 447-455

<sup>20</sup> T. Chira-Chavala and Christoffel Venter, "Cost and Productivity Impacts of a Smart Paratransit System:", *Transportation Research Record 1571*, Transportation Research Board, Washington, D.C. 1997, pg. 81-7

<sup>21</sup> Nakanishi, Yuko and Martinez, Manuel, "APTS Technologies and Rail Transit Productivity," ITS America Eighth Annual Meeting, May 4-7, 1998, Detroit, MI, ITS America, Washington D.C., 1998

types of AVL unless one had a large and expansive data set with a significant variation in AVL technologies across firms.

In order to distinguish the separate contribution of AVL and a particular type of AVL implemented we take the calculated TFP measure for each firm in each year and regress it on a set of variables that would influence the change in productivity. In doing it this way we net out the influence of other variables and obtain a more accurate measure of the separate contribution of AVL to firm efficiency. If significant, this would be included in any benefit-cost evaluation that might be undertaken.

Our TFP calculation is developed on a database (described in detail in the following section) for about 20 transit firms in the United States. These firms were selected to be approximately the same size and in some cases to have introduced AVL at some point over the last several years. Some agencies that do not use AVL and these were used as a control group in the regression estimation.

The TFP calculation considers that the transit firm can be seen as producing a number of different outputs. There are three measures considered; *total passenger trips*, *total passenger miles* and *total vehicle revenue miles*. They are not necessarily to be aggregated since they represent different ways of viewing what a transit firm does and what the objective function is. This is valuable since it also allows us to explore the idea that AVL may be more effective if certain types of transit policies are being pursued. Some firms may, for example, be trying to maximize ridership and set their fare and service policies accordingly. Others may be trying to maximize service quality measured as the number of vehicle miles provided in a given time period. The regression equation would be represented as:

$$TFP_{i,t} = f(\text{output, capital, time, AVL, AVL}_k, \text{firm dummy})$$

where  $TFP_{i,t}$  is a measure of total factor productivity of transit firm I in time period t, output is a measure of firm vehicle revenue miles or passenger miles or trips, time is a variable to capture any trend effects and AVL is the dummy variable indicating that AVL was used and if it is subscripted 'k' it is a dummy variable that indicates the particular type of AVL that was used. Using this approach we can determine first if AVL did affect firm productivity, second what its own contribution was controlling for other variables and finally, given that AVL was used is there a discernable difference in the productivity affects across different types of AVL systems?

### 3.2 Identifying the Enablers

Once the question of whether AVL does lead to statistically significant improvements in productivity, we need to be able to identify the factors that underlay the improvement in cost efficiency. As has been noted, AVL is an enabling technology that provides the opportunity for transit management to devise strategies and approaches to delivery that utilize the technology to lower costs and improve service levels. If we consider the factor inputs of capital, fuel, materials and labor, it may be possible to use less of any one or

each of them. The primary sources of agency benefits come about from improvements in fleet utilization, improvements in efficiency from the various categories of labor and the potential for reducing the number of vehicles (and their attendant drivers, maintenance requirements etc.) with no reduction in service.<sup>22</sup> The difficulty is that the specific relationships between the AVL control strategy and the improvement in cost and productivity are not well known. AVL represents a new technology and the effects are not well documented, quantitatively.

What is needed is a method of establishing the simple statistical relationships between costs and fleet reductions and revenue mile reductions and fleet requirements and schedule adherence. These would provide a means whereby it would be possible to measure the costs savings. More specifically, the impacts of AVL can more easily be calculated with information on the following relationships<sup>23</sup>:

The first equation attempts to link the size of the fleet of transit vehicles (fleet size) to a set of variables that can be impacted by AVL control strategies. These would include schedule adherence, number of revenue vehicle miles and other variables that would impact fleet size. The key variable for evaluation purposes is the schedule adherence. If it were possible to obtain information on these variables over time and across a number of transit agencies, it would be possible to ‘estimate’ values for  $b_1$  as well as  $b_2$  and the ‘ $b_i$ ’s’. The importance of knowing  $b_1$  is that it provides a measure of the change in (or impact on) fleet size with a unit change in the schedule adherence, holding other things constant (or controlling for the other influences).

$$\text{Fleet Size} = a + b_1 (\text{schedule adherence}) + b_2 (\text{revenue vehicle miles}) + \sum b_i (\text{other variables}) \quad (1)$$

In equation 2 a similar exercise is carried out as it was for equation 1. It is trying to understand what factors are most important in determining total operating costs. Notice there is a linkage between equation 1 and equation 2. The variable ‘fleet size’ appears in both equations but in equation 1 it is the variable that ‘is being explained’ while in equation 2 it is an ‘explaining’ variable. As in the case of the first equation, if there are enough data available to ‘estimate’ values of  $c$ ,  $d_1$ ,  $d_2$  and  $d_3$  using regression techniques, it is possible to determine how changes in fleet size will alter total operating costs. Therefore it would be possible to assess how the introduction of an AVL control strategy would affect operating costs using both equations 1 and 2.

$$\text{Total Operating Cost} = c + d_1 (\text{revenue vehicle miles}) + d_2 (\text{fleet size}) + d_3 (\text{number of transferring routes}) \quad (2)$$

Equation 3 the effect of the ‘variance in schedule adherence’ on output as measured by vehicle miles is examined. There are two important relationships here. First, is the direct effect of changes in AVL control strategies on vehicle miles. The parameter  $h_1$  would

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<sup>22</sup> It is also possible to translate this impact into a service level improvement but without and additional resources required.

<sup>23</sup> The relationships are represented as linear but there is no reason they necessarily should be.

measure how many added vehicle miles a transit firm could achieve with an improvement in schedule adherence. This is an improvement in output (hence performance) with no additional resources save those associated with the AVL strategy. There is also an indirect effect through the impact on total operating costs, equation 2. The sequence would run from the AVL control strategy affecting schedule adherence, which has an impact on vehicle miles which in turn has an effect on operating costs.

$$\text{Vehicle Miles} = g + h_1 (\text{variance in schedule adherence}) + \sum h_i (\text{other factors}) \quad (3)$$

In equation 4, the impact of AVL on one aspect of transit performance or service delivery of the transit firm is being explored. AVL control strategies can have an impact on schedule adherence and this can manifest itself in either lower costs or greater output or levels of service with no additional resources. The first three equations explored how AVL can result in lower costs either directly or through enhancements in productivity. In this equation the relationship is much more how output can be increased with no added resources except those expended on the AVL control strategy. If AVL improves schedule adherence it will allow the transit firm to use its existing resources to raise the level of service. This will have an impact on transit users and would certainly be counted as a benefit of the AVL system.

$$\text{Revenue Miles} = e + f_1 (\# \text{ of routes}) + f_2 (\# \text{ transfer points}) + f_3 (\text{schedule adherence}) \quad (4)$$

These four relationships are just a beginning in establishing relationships that provide insight as to how AVL control strategies affect transit efficiency and performance. Given the appropriate data, the equations set out will identify the fleet reduction available with changes resulting from AVL, the reduction in revenue miles available with AVL and how cost would change with changes in revenue miles.

#### 4 DATA DESCRIPTION

Firms were considered for selection based on their use of AVL, their comparability with an AVL agency and the availability of useful data for the agency. Our final list contained twenty-three agencies, with data for each agency covering the years 1988-1997. Data for each agency was collected from the Federal Transit Authority (FTA). The Section 15 reports, later referred to as the National Transit Database, contain financial and operational information for all transit agencies in the country, regardless of size or location. This information is available in print, and it is also available for download for years after 1992 ([www.fta.dot.gov](http://www.fta.dot.gov)).

Before we reached the final list of agencies, we examined a much larger list of possible agencies. Information regarding agency use of AVL was based on information from the *Synthesis of Transit Practice 24: AVL Systems for Bus Transit, Advanced Public Transportation Systems Deployment in the United States*, and *Advanced Public Transportation Systems: The State of the Art, Update 1998*. We were able to find the

agencies that had AVL systems up and running on a regular basis. This report focused on the use of AVL on fixed route motor bus services. The use of AVL in direct response services was not covered here to maintain consistency.

The following agencies were included in the final study.

**Table 1**  
**Transit Agencies Included in Study**

Agencies Included in AVL Study			
FTA Identification Number	State	Agency Name	AVL Carrier
0001	WA	Seattle-Metro	Yes
0011	ID	Boise Urban Stages	No
1001	RI	Providence-RIPTA	No
1066	VT	Burlington-CT	No
2113	NY	Rochester-RTS	No
3034	MD	Baltimore-Maryland-MTA	Yes
4027	FL	St. Petersburg-PSTA	No
4029	FL	Ft. Lauderdale-Bct	No
4032	FL	Daytona Beach-VOTRAN	No
4041	FL	Tampa-Hartline	Yes
4046	FL	Sarasota-SCTA	No
5012	OH	Cincinnati-SORTA	No
5016	OH	Columbus-COTA	No
6011	TX	San Antonio-VIA	Yes
7003	MO	Springfield-CU	No
7005	MO	Kansas City-KCATA	Yes
7006	MO	St. Louis-Bi-State	No
8001	UT	Salt Lake City-UTA	No
8006	CO	Denver-RTD	Yes
9008	CA	LA-Santa Monica	Yes
9013	CA	San Jose-SCCTD	No
9016	CA	SF-Golden Gate	No

A review of these articles offered important information regarding the installation status and use of various AVL systems. For example, we eliminated San Francisco's MUNI from consideration when we discovered MUNI only uses its AVL systems for emergency response, not for planning or data collection. As well, we were able to find out the number of years that a system was employed and on the number of buses. This information helps us understand the stage of AVL implementation. In Baltimore, there were both a preliminary test of a Loran-C AVL system and the installation of a full GPS system at the end of 1996.

These articles provided the AVL technology employed, the year it was introduced and the number of buses equipped with AVL. With this information, we were able to create three columns of information. The column AVL dummy shows what years AVL was employed, where a One shows that AVL was in place. The second column which technology was used, information used in secondary regressions to compare the effect of the different technologies implemented. The final column shows the amount of buses using AVL, such that partial deployments can be analyzed.

Agencies for consideration also need to be examined based on their comparability. Criteria included network size, regional population, geography, and size of agency. The FTA organizes reports for agencies by the size of their 'urbanized area' (UZA). As a result, a broad range of agencies was included in the final data set. The fact that Seattle and Santa Monica are both AVL carriers are reviewed (over 800 and approximately 125 buses respectively) requires that many agencies of varying sizes be included for comparison.

The main reason agencies were not included in the final data set came from shortcomings in the available data. Unfortunately, two firms using AVL had to be excluded from consideration due to inadequate labor input information. Other agencies to be included for comparison also were also removed due to data shortcomings. Chapter 2 of the National Transit Database warns that "analysis of expenses by function must be qualified by the degree to which transit agencies uniformly allocate expenses among the various functional categories" (Section 2.4). The fact that we encountered agencies with unacceptable vehicle-operations information is, therefore, not surprising.

**Table 2**

**Agencies Excluded from Study of AVL**

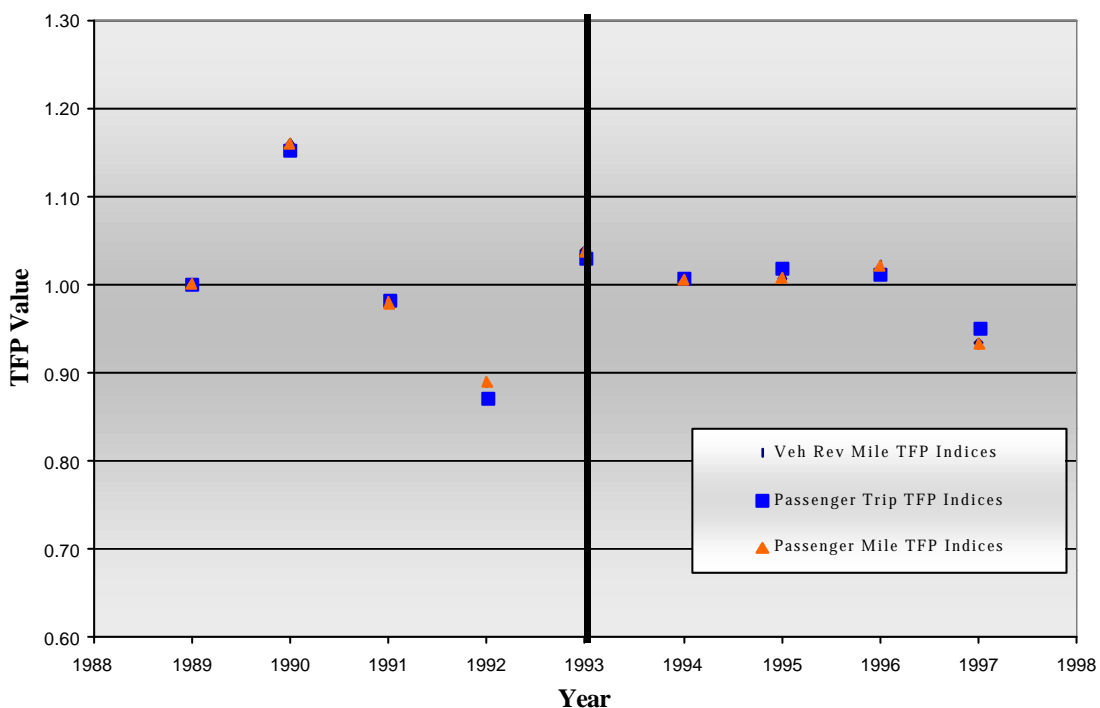
<b>Agency ID Number</b>	<b>State</b>	<b>Agency Name</b>	<b>Reason for Exclusion</b>
2076	NY	Westchester Co. DOT	Incomplete vehicle-operation cost inputs, SECTION 15 TABLE 3.08.1. AVL user.
3023	PA	Beaver County TA	Incomplete vehicle-operation cost inputs, SECTION 15 TABLE 3.08.1. AVL user.
9015	CA	San Francisco MUNI	AVL system only used for emergency response
9016	ME	Portland-METRO	No fleet information, non AVL
2010	NY	Poughkeepsie-LOOP	No fleet information, incomplete labor information, non AVL
2080	NJ	New Jersey Transit	No fleet information, non AVL
2010	NY	Clarkston Mini-Trans	No fleet information, incomplete labor information, non AVL
3042	MD	Hagerstown Commuter	No fleet information, incomplete labor information, non AVL
6016	TX	Beaumont-BMT	No fleet information, incomplete labor information, non AVL
9030	CA	San Diego-NCTD	No fleet information, non AVL

#### 4.1 A Preliminary Examination of AVL and Productivity Impacts

Before the formal examination of TFP is developed, it is sometimes considered useful to examine the 'gross' TFP values. They are gross in the sense they incorporate all the physical, environmental and economic influences. Nonetheless, it is a useful first step to see the variability over time and across agencies in the TFP measures. We also relate them to the year the AVL was introduced. This is useful since it makes clear why a subsequent statistical analysis is necessary. A downturn in TFP after the introduction of AVL might lead to the [erroneous] conclusion that AVL is counterproductive. However, many other things are happening in the economy at the same time as AVL introduction.

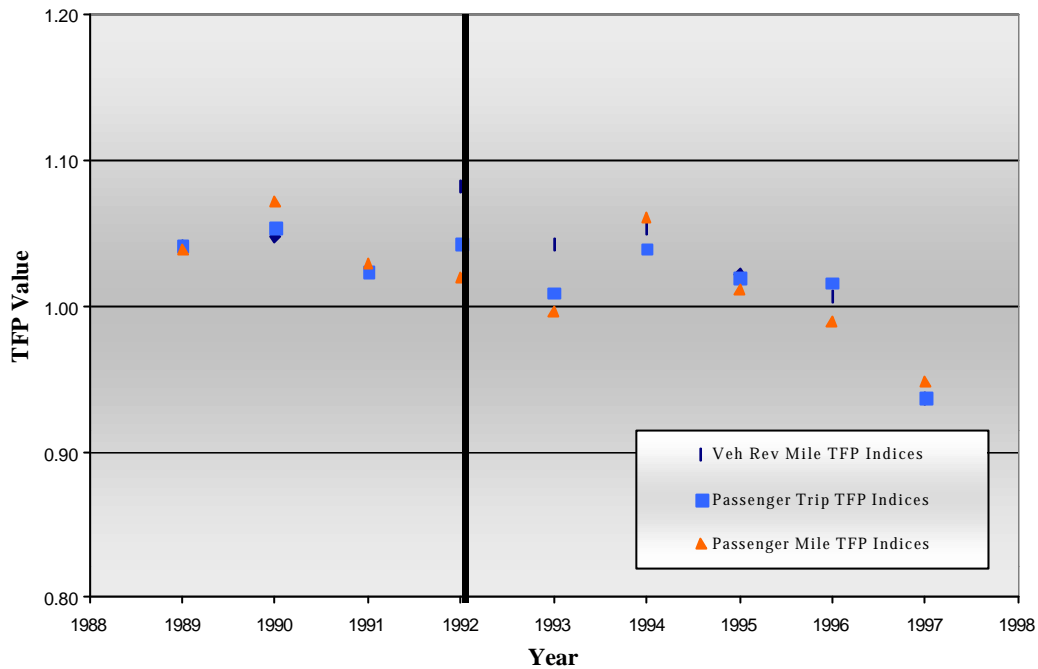
The following graphs show the change in TFP for each of the firms using AVL. One of the clearest trends which can be seen is the variability of the indices. Not only is there a good deal of variability amongst the agencies under consideration, there is also considerable change within each agency's time series. We cannot draw direct information from these graphs regarding the affect of AVL on the firms' efficiency. We should recall the total number of variables used to calculate TFP is quite large, therefore AVL's impact may or may not be sizable. That issue will be addressed later in the paper.

*Seattle Metro TFP Indices, AVL Introduced 1993*





*LA-Santa Monica TFP Indices, AVL Introduced 1992*

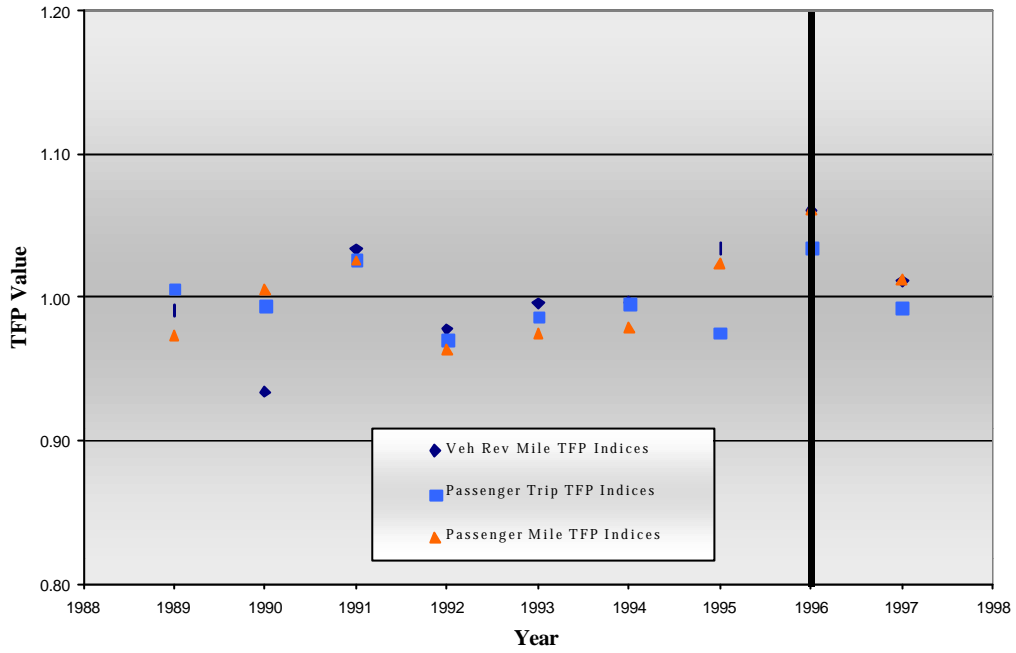


Seattle Metro's TFP indices track each other very closely each year, before and after the introduction of AVL in 1993. This is definitely the exception among the AVL firms' TFP measurements. The indices vary prior to 1993, but from that point on maintain a fairly consistent value near 1.0, with a slight decrease in the final year of the study.

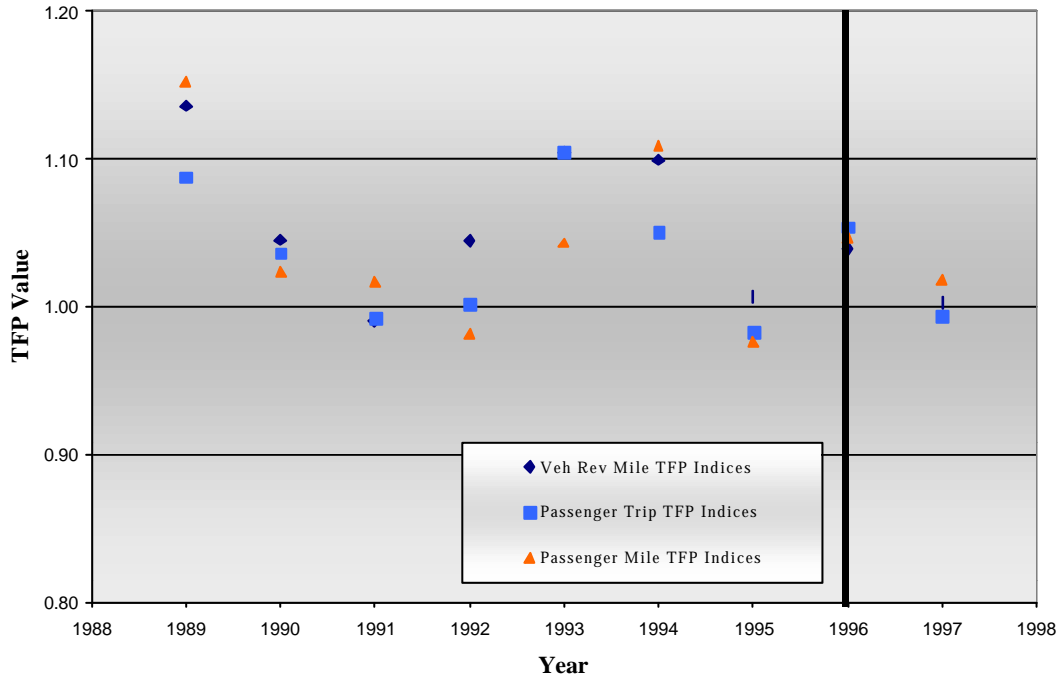
Santa Monica's TFP indices are mostly above one throughout the years of the study. Only in the final year do all of the measures dip below one. While there is some variability between years, most of the values hover around 1.03-1.05. Few agencies had as many index values above 1.0. While the number do trend down after the introduction of AVL in 1992, recall that this does not suggest that AVL has harmed the firm's productivity. This trend is a result of the many factors which go into the analysis.

Denver's transit service introduced AVL in 1996, the same year that the firm's TFP measurements reached their greatest value. The firm's indices varied until 1992, when they steadily increased until 1996. Again, we see a drop after the implementation of AVL. As noted above, we should not consider this to be a reflection of AVL's performance.

*Denver TFP Indices, AVL Introduced 1996*



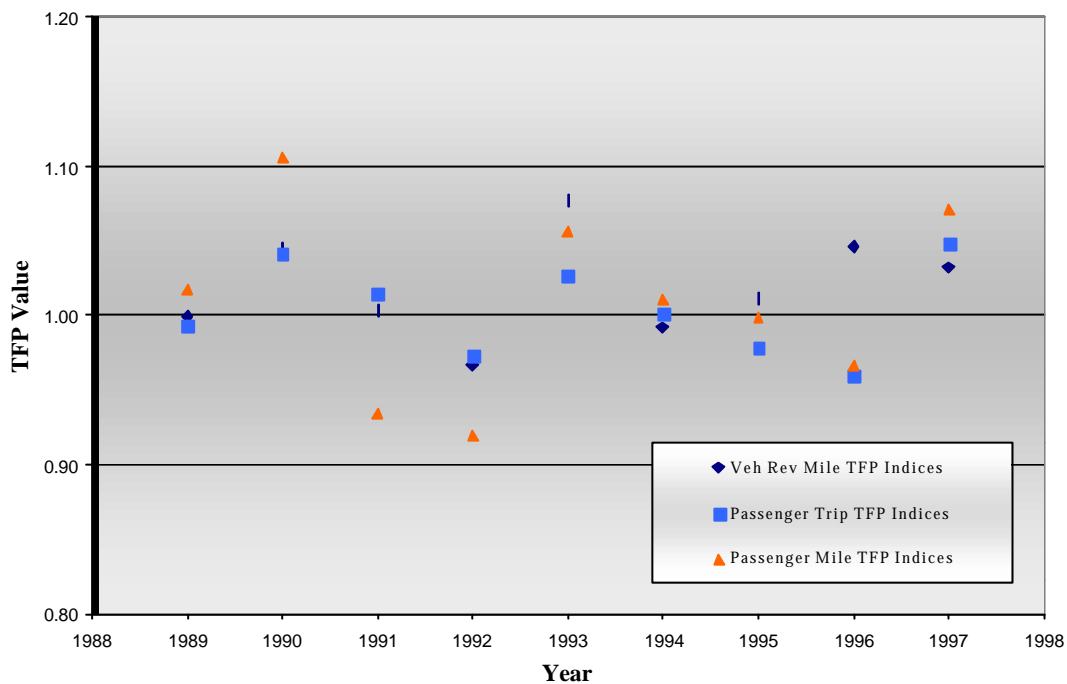
*Kansas City TFP Indices, AVL Introduced 1996*



The Kansas City agency, which introduced their AVL system in 1996, shows some of the most inconsistent TFP values of all the firms considered. Not only is there a great deal of

variability across the years, the index values also change rank from year to year. With the exception of 1993 and 1994, the values do seem to suggest a downward trend in TFP over the period of the study.

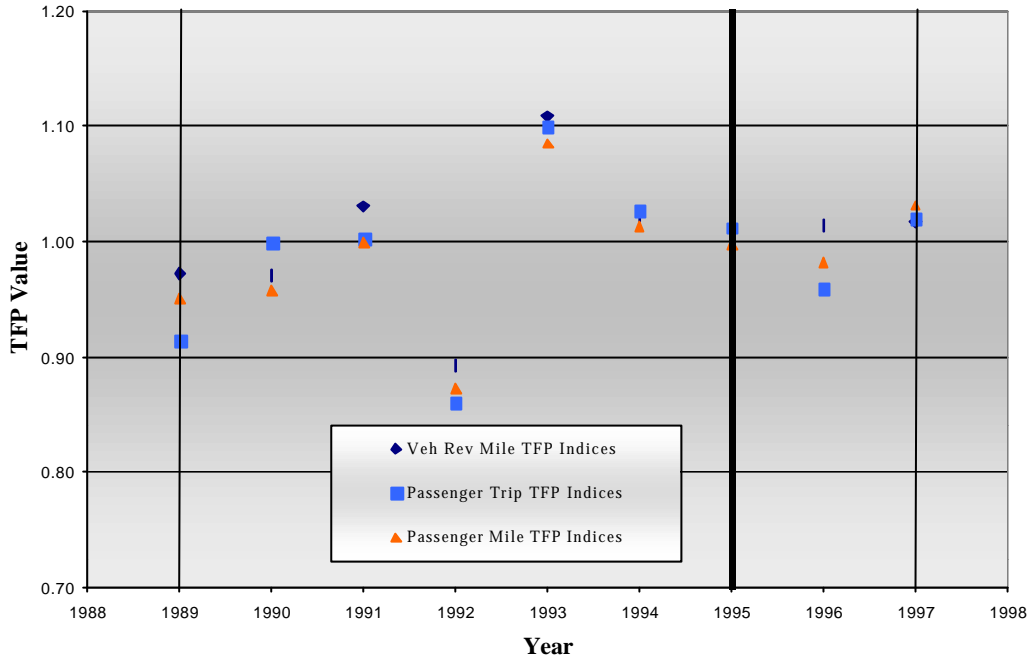
*San Antonio TFP Indices, AVL Introduced 1988*



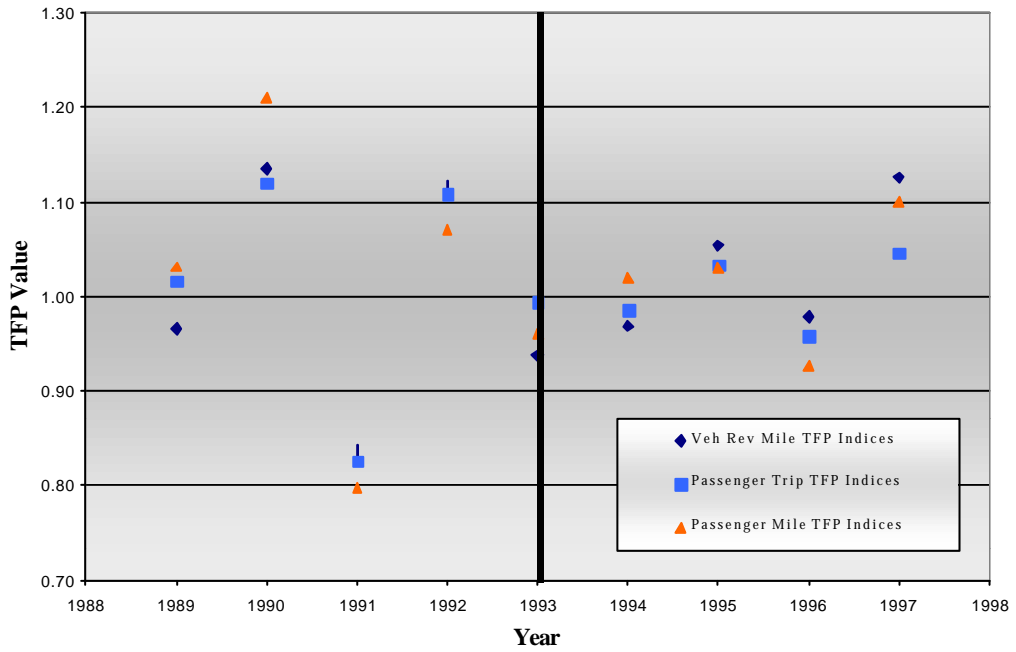
San Antonio's transit agency had an operational AVL system from the beginning of the study. While TFP is slowly trending upwards over the years, we see a great deal of inconsistency in the Passenger Mile TFP values until 1992. The Vehicle Revenue Mile and Passenger Trip indices consistently track a value of 1.0, though VRM does trend up over the last four years of the study.

Baltimore's transit agency actually had two different periods using AVL. From 1989-1995, they tested a Loran-C system on 50 buses in their fleet. Having deemed the test successful, Baltimore then invested in a complete GPS system installed at the end of 1996. The most noticeable characteristic of the TFP indices is the values observed in 1992. It would seem these values do not reflect the overall trends in TFP for the agency, which otherwise trend upward to 1993, before steadying around 1.0. Further study may reveal the circumstances which led to the values we see in 1992.

*Baltimore-Maryland TFP Indices, AVL 1989-95, 1997*



*Tampa-Hartline TFP Indices, AVL Introduced 1993*



Tampa's TFP values range from the relatively high values observed in 1990 to the low values we see in 1991. Overall, values trended downward from 1990 to 1993, when AVL is introduced. Steady growth is seen over the last five years of the study. The indices do track one another closely, though there is a relatively large amount of fluctuation over the years.

#### 4.2 Description of aggregate data

Information on employee work hours is broken down into four categories: vehicle operations, vehicle maintenance, non-vehicle maintenance, and general administration. While the precise allocation of work hours among these categories may vary among agencies, they do reflect the relative importance of the labor inputs. This information can be found in the 'Employee Input Quantities' table.

Fuel and material information is taken from the 'Operating Expenses by Service Type' table. Both fuel and materials are given, where materials inputs and costs consist mainly of tires and maintenance parts for the equipment. Since many agencies use both diesel and gasoline, fuel consumption was converted into BTUs (British thermal units).

This table also offered information on additional expenses, such as utilities paid, fringe benefits and insurance costs. Purchased transportation, also included, is an expense some agencies incur due to contracting services. In these cases, private firms are employed by agencies to help offer a greater quantity and quality of service.

Information regarding the capital stock of the agencies in question came from the "Transit Vehicle Data Book, 1998" published by the American Public Transit Association. Model, make, year, length and seat information is available for nine of the years in question; however, we did not have the 1988 information, so a least squares regression was used to estimate these values. From the data supplied, a summation of total vehicles and total seats was created for each year of the study. This allows two different input measurements for consideration: total vehicles per year and total seats per year.

Lastly, the data for the output measurements (vehicle revenue miles, passenger trips and passenger miles) come from the 'Transit Service Supplied' table in the National Transit Data base.

Graphs of inputs and outputs for TFP calculations have been placed in an appendix at the end of the report. Included below are some of the trends observed in the data, as well as a description of the TFP indices for non-AVL agencies.

#### 4.2.1 DESCRIPTION OF TRENDS FOR OUTPUT INDICATORS, INCLUDING VEHICLE REVENUE MILES, PASSENGER TRIPS AND PASSENGER MILES:

##### **LA- Santa Monica**

Evaluation of LA-Santa Monica output indicators yields no clear conclusions or trends - all three dip slightly with the introduction of AVL and climb a bit in the next few years.

##### **Denver**

The overall trend of indicators for Denver is upward. Vehicle revenue miles and passenger trips show gradual increases throughout the time period 1988-1997, and passenger miles shows a marked increase from 1994 on, with the trend continuing after AVL is introduced in 1996.

##### **Tampa**

Indicators for Tampa give little impression of a major underlying trend. Passenger miles jump sporadically before and after the introduction of AVL technology, while vehicle revenue miles and passenger trips climb gradually after AVL's introduction, only to sink gradually after a few years.

##### **San Antonio**

San Antonio's passenger mile figures show some variability from year to year, but remain largely within a narrow range throughout the study's time. Passenger trips and vehicle revenue miles stay at roughly the same level from 1988 on.

##### **Seattle**

Seattle's figures trend upward during the examined period. Vehicle revenue miles and passenger trips both show gradual growth before and after the introduction of AVL in 1993. On the other hand, passenger miles rise noticeably faster with AVL.

##### **Kansas City**

Overall, output indicators for Kansas City trend down during 1988-1996. Passenger trips and vehicle revenue miles show moderate decreases leading up to the implementation of AVL in 1996 and then show a slight recovery in 1997. Both the trend down and the recovery are more marked in passenger miles.

##### **Baltimore**

Output indicators here show a downward trend for the years in question. Passenger miles show the clearest downward tendency, falling steadily before, during, and after AVL implementation. This tendency is also reflected in passenger trips, although in a much more subtle way. Vehicle revenue miles hold relatively steady throughout.

#### 4.2.2 DESCRIPTION OF TRENDS AMONG TFP INDICES:

##### **Providence**

TFP indices for Providence give no clear picture of a trend. All three jump around in a range of 0.8-1.2.

##### **Burlington**

All three indices show increases in the years 1988-1993, and then slight decreases until 1997, where they jump sharply up.

##### **Rochester**

The years 1988-1993 show little direction, although values tend to linger just above or below 1. Thereafter, indices show clear growth until 1997, when they fall sharply.

##### **St. Petersburg**

St. Petersburg's TFP figures jump around to a fair extent, but the three tend to track each other closely and rise in the years 1991-94.

##### **Ft. Lauderdale**

Figures here hover around 1, with the exception of 1992, when they jump sharply upwards. Once again, all three indices track each other closely and consistently.

##### **Daytona Beach**

TFP values here fall moderately in the years 1990-94, and then rise to hover above 1 thereafter.

##### **Cincinnati**

Cincinnati's TFP figures move upward in the first 3-4 years surveyed, fall for the next few, and rise during 1993-97.

##### **Columbus**

TFP figures for Columbus fall consistently in the first 5 years of the data set, and climb slightly thereafter.

##### **Springfield**

TFP values here show a jump in 1989, a consistent and significant fall during 1989-1994, and a recovery thereafter.

##### **St. Louis**

St. Louis' TFP figures show no real trends, varying largely within the range .9-1.1.

##### **Salt Lake City**

Salt Lake City's TFP values show a downward trend in the years 1989-94, and then rise slightly.

### **Sarasota**

Figures here tend to hover at or just above a value of 1, with no marked trends.

### **San Jose**

TFP indices for San Jose tend to hover in the range 1-1.1.

### **SF-Golden Gate**

TFP indices here track each other very closely and, with the exception of those for 199, hover just above 1.

### **Boise**

Boise's TFP figures show a demonstrable drop in the years 1993-97, with the exception of 1995, where they jump sharply up.

## **4.2.3 TRENDS OBSERVED IN VEHICLE REVENUE MILES:**

### **Large Agencies**

Most agencies seem to have consistent levels of vehicle revenue miles, with the exception of Seattle, which sees slight growth, and Baltimore, which sees a slight drop.

### **Medium-Sized Agencies**

With the exception of Salt Lake City, which sees consistent and significant VRM growth during the years in question, most agencies have a consistent output level.

### **Small Agencies**

While the small agencies such as Boise and Burlington seem to have steady VRM output levels, others such as SF-Golden Gate or St. Petersburg experience growth, while Tampa sees a downturn in VRM output.

## **4.2.4 TRENDS OBSERVED IN PASSENGER TRIPS:**

### **Large Agencies**

Most of the agencies hold relatively steady over time in terms of passenger trips as output. However, Baltimore does show limited decline, while Seattle experiences growth.

### **Medium-Sized Agencies**

Other than Salt Lake City and Ft. Lauderdale, which see consistent passenger trip growth, and Kansas City, which sees its numbers fall off a bit, agencies in this category remain relatively stable.

### **Small Agencies**

The small agencies, such as Sarasota and Daytona Beach, show a tendency to grow during 1988-97, while other, larger ones in the category, such as St. Petersburg and Tampa, see almost no change.



#### 4.2.5 TRENDS OBSERVED IN ANNUAL PASSENGER MILES

##### **Large Agencies**

Most large agencies maintain a consistent level of passenger miles as output, while Seattle and Denver see significant growth. Baltimore, as with other output measurements, shows some decline in passenger miles.

##### **Medium-Sized Agencies**

Most of the medium-sized agencies seem to fluctuate around their respective means, while Ft. Lauderdale shows consistent growth and Columbus falls off a bit.

##### **Small Agencies**

As for passenger trips, the very small agencies tend to grow slightly during the surveyed years, whereas the slightly larger - but still small - agencies exhibit variation around their respective means.

#### 4.2.6 FUEL AND LUBE, ADMINISTRATIVE COSTS FOR AVL FIRMS:

##### **Tampa**

Tampa's fuel and lube costs seem to hold steady over the years surveyed, while administrative costs jump significantly with the introduction of AVL in 1993.

##### **LA-Santa Monica**

Fuel and lube costs remain relatively steady, while administrative costs seem to grow with the introduction of AVL in 1992.

##### **Baltimore**

Baltimore's fuel and lube costs are steady over time, while administrative costs demonstrate a rising trend - with the exception of 1991's sharp fall.

##### **Kansas City**

Once again, fuel and lube costs seem to waver around the same level over time, while administrative costs rise sharply with AVL in 1996-7.

##### **San Antonio**

Fuel and lube costs for San Antonio rise gradually over time, while administrative costs rise significantly.

##### **Denver**

Fuel and lube costs remain relatively stable over time, while administrative costs rise moderately.

##### **Seattle**

Seattle's fuel and lube costs seem stable, while administrative costs rise sharply until the introduction of AVL in 1993, and fall off thereafter.

#### 4.3 Issues relating to the data used

There are number of important features of the data that must be kept in mind when using the information. Operating expenses, for example, are reported using accrual accounting, which means that operating expenses are reported for the year they were incurred. Therefore, they are reported regardless of payment for such services. Analysis of expenses by function must be qualified by the degree to which transit agencies uniformly allocate expenses among the various functional categories. This analysis should include careful consideration of reporting limitations as well as detailed accounting practices at the specific transit agencies examined.

Passenger mile data are not usually collected as a routine part of operations. Due to the difficulties associated with gathering this information, sampling is employed by the transit agencies to estimate this information. While a number of sampling methods are employed, they must ‘satisfy precision and confidence level requirements of 10 percent and 95 percent, respectively.’

Data presented in the employee work hours tables must be considered carefully. Employee work hours include hours worked by both full-time and part-time employees. It is also important to consider that some services are provided on a contractual basis and therefore are not reported directly by the agency. For example, Boise’s transit agency shows zeros for non-vehicle maintenance from 1994-1997. It is likely that these services were contracted out to either a private party or another municipal entity.

The introduction of new technologies, such as AVL, take place in a dynamic environment. Many things are changing including macroeconomic factors such as employment and inflation, personal incomes, household formation, land development, gasoline prices and levels of transportation system use. In order to assess whether AVL, or any other specific factor, has had an impact on agency productivity, a more detailed analysis is required. An analysis that is able to net out the affects other than AVL. This is carried out in the following section.

## 5 EMPIRICAL RESULTS

The TFP measures reported in section 5 provide an indication of how *gross* TFP changed within each firm over time. However, as we have already noted, it is not possible to either compare the TFP measures across firms or to identify the net contribution of introducing AVL for each firm. Comparisons cannot be across firms because differences in the operating environment may lead to higher or lower values of TFP and have little or nothing to do with management decisions. Once one controls for differences in these factors, a *residual* TFP measure can be compared across firms.

In section 4 the different regressions were described for investigating both the impact of AVL on TFP, which would at the same time control for other environmental and

structural differences, and the identification of drivers or enablers of how AVL affects cost efficiency.

### 5.1 Measuring the Impact of AVL

There are three measures of TFP used in this analysis. TFPVRM uses vehicle revenue Miles as the output unit, TFPPM uses Passenger Miles and TFPPT uses passenger trips. The TFP regressions were estimated for each of these output measures. Table 3 and Table 4 provide the empirical results from the estimation of a log-linear model of TFP on environmental, structural and managerial variables. In both tables the  $R^2$  is relatively low indicating that only between 14 and 26 percent of the variation in the dependant variable, TFP, is accounted for by the set of variables included in the regression. Nonetheless, the set of variables includes *Vehicle Miles* as a measure of output to take account of differences in both the size and utilization rate of capital. This variable is significant and has an elasticity value of 0.027.<sup>24</sup> While the impact is small, it shows a 10 percent increase in passenger miles would increase TFP by approximately .3 percent. Thus, the evidence seems to be that expanding passenger miles will not lead to large increases in cost efficiency. If we examine Table 4, the same variable has a quite similar value when the dependant variable is TFP using Revenue Vehicle Miles as the measure of output. The variable *Buses* was used as a measure of the amount of capital stock. The positive value indicates the transit firms have too few buses but the magnitude of the coefficient is quite small. With the variation across firms and the lack of significance in the TFPVRM regression (Table 4), one might argue that too little capital is too strong an interpretation. The time variable in both tables is negative and significant, indicating that over time productivity at the transit firms has been falling. This is consistent with the evidence from a number of other studies.

The remaining variables reported in the tables are dummy variables. This means they are shift effects and depending on the sign of the variable they would increase or decrease the value of the regression equation. Transit specific dummies are listed for Baltimore through St. Louis. The majority of the variables are statistically significant (have a t-value >1.6) and there is a mixture of positive and negative signs.

The variable of most interest is the *AVL* dummy. In both equations the variable is statistically significant and has a positive sign. This is a significant finding. It indicates that the introduction of AVL had a positive impact on transit firm productivity. We can also see that the positive productivity affect is larger when output is measured by Passenger Miles than when it is measured by Vehicle Revenue Miles, in fact the value of the coefficient is almost double. One can speculate that in instances where the transit manager has an objective of maximizing service levels that AVL is of less consequence since using extra resources is of less importance or concern. When the manager's objective function is to maximize passenger miles, it has to work through fare levels and

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<sup>24</sup> In a log linear regression the coefficients can be interpreted as elasticities; the degree of responsiveness of the dependant variable with a change on the variable whose coefficient we are talking about.

service quality. Improving productivity and developing better service information can be obtained through the use of AVL.

**Table 3**  
**TFP Regression Using Passenger Miles**

Dependent Variable: <b>LOG(TFPPM)</b>			
Sample(adjusted): 3 198			
Included observations: 196 after adjusting endpoints			
Variable	Coefficient	Std. Error	t-Statistic
Constant	48.944	29.867	1.639
LOG(Vehicle Miles)	0.027	0.017	1.611
LOG(Buses)	0.036	0.021	1.755
LOG(Year)	-6.524	3.969	-1.644
AVL	0.022	0.008	2.702
Baltimore	-0.141	0.064	-2.208
Boise	0.130	0.116	1.122
Chitt	0.123	0.122	1.008
Cincinnati	-0.048	0.030	-1.585
Columbus	-0.032	0.025	-1.273
Denver	-0.106	0.058	-1.823
Ft. Lauderdale	0.008	0.039	0.206
Golden Gate (SF)	-0.024	0.025	-0.978
Hills	-0.023	0.031	-0.740
Pinellas	-0.033	0.041	-0.803
Providence	-0.026	0.025	-1.036
Rochester	-0.010	0.028	-0.345
San Antonio	-0.109	0.056	-1.943
San Jose	-0.053	0.051	-1.033
Santa Monica	0.012	0.042	0.286
Sarasota	0.130	0.104	1.255
South daytona	0.068	0.091	0.745
Seattle	-0.131	0.071	-1.849
Salt Lake City	-0.096	0.043	-2.252
Springfield	0.091	0.107	0.855
St. Louis	-0.079	0.052	-1.523
AR(1)	-0.372	0.076	-4.897
AR(2)	-0.219	0.077	-2.857
Adjusted R-squared			
	0.267887		
S.E. of regression			
	0.077275		
Sum squared resid			
	1.003196		
Log likelihood			
	238.8306		
Durbin-Watson stat			
	2.05135		
F-statistic			
	1.526005		

**Table 4**  
**TFP Regression Using Vehicle Revenue Miles**

Dependent Variable: **LOG(TFPVRM)**

Sample(adjusted): 3 198

Included observations: 196 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic
Constant	-4.2710	21.3112	-0.2004
LOG(Vehicle Miles)	0.0203	0.0134	1.5110
LOG(Buses)	0.0433	0.0314	1.3794
LOG(Year)	-0.5111	0.3330	-1.5350
AVL	0.0097	0.0042	2.3161
Baltimore	-0.1156	0.0450	-2.5711
Boise	0.0967	0.0807	1.1984
Chitt	0.0935	0.0851	1.0993
Cincinnati	-0.0367	0.0208	-1.7661
Columbus	-0.0255	0.0173	-1.4720
Denver	-0.1014	0.0406	-2.4954
Ft. Lauderdale	-0.0092	0.0278	-0.3320
Golden Gate (SF)	-0.0231	0.0169	-1.3690
Hills	-0.0267	0.0212	-1.2569
Pinellas	-0.0029	0.0290	-0.1005
Providence	-0.0143	0.0171	-0.8366
Rochester	-0.0051	0.0192	-0.2639
San Antonio	-0.0819	0.0391	-2.0931
San Jose	-0.0591	0.0354	-1.6667
Santa Monica	0.0138	0.0287	0.4819
Sarasota	0.0821	0.0729	1.1272
South daytona	0.0496	0.0642	0.7728
Seattle	-0.1075	0.0493	-2.1803
Salt Lake City	-0.0657	0.0295	-2.2291
Springfield	0.0903	0.0747	1.2086
St. Louis	-0.0581	0.0362	-1.6065
AR(1)	-0.4888	0.0730	-6.6932
AR(2)	-0.3113	0.0737	-4.2257
Adjusted R-squared	0.148518		
S.E. of regression	0.059639		
Sum squared resid	0.597552		
Log likelihood	289.6048		
Durbin-Watson stat	2.082572		
F-statistic	2.259717		

The AR(1) and AR(2) variables reported in the tables are first and second order parameters from the auto regressive model used to control for serial correlation. The Durbin-Watson statistic should be around 2. If it is less than 2 it indicates positive serial correlation and a value  $>2$  indicates negative serial correlation.

The type of AVL system put in place was also examined. Using a specification similar to that in Table 3 and Table 4, dummy variables identifying the different types of AVL technologies that different transit firms employed were used in the regression. In all cases for all measures of TFP there was no case in which a particular AVL technology was statistically significant. The regression contained both the AVL dummy variable indicating that an AVL system was being used as well as the series of dummy variables identifying the particular technologies. The proposition was, 'does the use of AVL matter, and if so, does it matter which one that is used'? The answer to the first question we have seen is yes. We discovered the answer to the second question is no; at least with the data set employed here.

## 5.2 Identifying the Drivers of AVL on Cost Efficiency and Service

The TFP regressions provided the evidence that the AVL has a positive affect on productivity. This information would be used in a benefit cost study to account for the beneficial impact on productivity. However, from a management strategy perspective as well as public policy it is useful to identify 'how' the use of AVL may make a difference. We explored several cost and revenue relationships.

### 5.2.1 CUSTOMER SERVICE

AVL, as noted at the outset, can provide information to transit managers that can lead to better customer information on when buses will arrive and how long a wait might be expected. This allows people to better plan the use of their time but also allays apprehension. It can provides a measure of service quality as well since reducing the variance in schedule adherence is a signal of higher commitment to customer service.

Table 5 reports the result of the examination of changes in the number of passenger trips in a system as a result of environmental and managerial variables. The first point to observe is that the  $R^2$  is quite high with the set of variables explaining 98 percent of the variation in passenger trips. As before the specification is log-linear so the coefficients can be read as elasticities. The *year* variable is not quite significant but the *vehicle mile* and *buses* variables are. The elasticity of passenger trips with respect to vehicle miles is 0.67 indicating that a 1 percent increase in vehicle miles of service will, on average, lead to a .6 percent rise in passenger trips. As the number of buses increases (a 1 percent rise, for example), a measure of the size of the capital stock and capacity availability, passenger trips increase by 0.4 percent.

**Table 5**

**Regression of AVL on Passenger Trips**

Dependent Variable: <b>LOG(PAXTRIP)</b>			
Sample: 197 obs			
Variable	Coefficient	Std. Error	t-Statistic
Constant	-11.50163	67.17895	-0.171209
LOG(YEAR)	1.978961	1.848412	1.070628
LOG(Vehicle Miles)	0.673058	0.08787	7.659702
LOG(Buses)	0.425511	0.088216	4.823513
AVL (dummy)	0.180909	0.043006	4.206599
AR(1)	0.879024	0.035694	24.62666
Adjusted R-squared	0.985996		
S.E. of regression	0.153967		
Sum squared resid	4.527803		
Log likelihood	92.10635		
Durbin-Watson stat	1.891029		
F-statistic	2761.09		

The more important variable of interest is the apparent impact of the use of AVL. As before in the TFP regressions, AVL is introduced as a dummy variable and therefore shifts the regression equation, in this case positively. The use of AVL leads to increased passenger trips and by a non-trivial amount. Unfortunately, because we do not have details on transit firm's operations, routes, scheduling etc. it is not possible to explore further as to how the increase in passenger trips is accomplished. Nonetheless, AVL does have a positive benefit on passenger trips.

**5.2.2 COST EFFICIENCY**

Proponents of AVL have argued that the principal benefit of it is to allow transit managers to better utilize resources, that is to generate cost savings. In an industry that generally does not cover its operating costs, improving efficiency is an important goal.

In our investigation, the first task was to establish whether the use of AVL had an impact on costs and if so how. In Table 6, the results of the regression of a set of environmental and managerial variables on cost per vehicle mile are displayed. The function was specified in log-linear form and estimated over the entire sample of data. The  $R^2$  is .83 meaning 83 percent of the variation in cost per vehicle mile are explained by the set of variables included in the estimation.

The *vehicle miles* variable is a measure of output for the transit firm, it is what the firm supplies to the market. The elasticity of cost is 0.25; a 1 percent increase in vehicle miles increases costs by .25 percent. This is a reasonable figure and indicates there are cost

**Table 6**  
**Regression of Cost per vehicle Mile and the Impact of AVL**

Dependent Variable: <b>LOG(COSTPVM)</b>			
Sample(adjusted): 2 198			
Included observations: 197 after adjusting endpoints			
Variable	Coefficient	Std. Error	t-Statistic
Constant	-720.2199	59.80969	-12.04186
LOG(Year)	95.22308	7.878391	12.08662
LOG(Vehicle Miles)	0.258805	0.076543	3.381171
LOG(Buses)	0.422678	0.076766	5.506057
AVL	-0.054009	0.031698	-1.703861
AR(1)	0.810723	0.0425	19.07584
Adjusted R-squared			
	0.830795		
S.E. of regression			
	0.133162		
Sum squared resid			
	3.386848		
Log likelihood			
	120.7046		
Durbin-Watson stat			
	1.983936		
F-statistic			
	193.4722		

economies, as one would expect since most transit firms have some excess capacity. The variable 'buses' is a measure of the size of the firm, an indicator of its capital stock. The positive coefficient is what we would expect.

The AVL variable is entered as a dummy indicating the presence or absence of the use of AVL in the transit agency. It will shift the cost function up or down depending on whether it has a positive or negative sign, respectively. In our estimation the negative sign indicates AVL has the effect of lowering costs.

How costs are reduced is the next question examined. In the previous discussion, AVL was supposed to allow better utilization of equipment, better planning and the ability to deliver the desired level of service with fewer resources. Each of these issues was investigated using our transit data set. Three models provided some explanation of the source of the cost savings. They relate to the size of the bus fleet, the amount of energy used to provide passenger trips and vehicle miles of service and the amount of labor used



in operations maintenance, particularly the bus fleet. The results are displayed in Table 7 through Table 9.

In Table 7 the impact of AVL on the bus fleet is examined. Once the amount of output and level of service are accounted for, do we observe a negative affect of AVL on the number of buses in the fleet, across transit firms? In the estimation both *passenger trips* and *vehicle miles* lead to an increase in the number of buses used. As one would expect an increase in passenger tips leads to a proportionately less increase in the number of buses used relative to an increase in vehicle miles. The elasticity of fleet size with respect to passenger trips is 0.25; a 1 percent rise in passenger trips leads to a .25 percent increase in the number of buses, in the fleet, on average. On the other hand, the elasticity of fleet size with respect to vehicle miles is 0.69, almost double the passenger trip elasticity. A 1 percent increase in vehicle miles leads to a 0.69 percent in buses used. This is as one would expect since producing more vehicle miles either because of greater geographic coverage or higher frequencies requires more vehicles. Adding more people can utilize the existing capacity since the average load factor is about 30 percent across transit agencies in the sample.

**Table 7**  
**Regression of Bus Fleet Size and AVL**

Dependent Variable: <b>LOG(BUSES)</b>			
Sample(adjusted): 2 198			
Included observations: 197 after adjusting endpoints			
Variable	Coefficient	Std. Error	t-Statistic
Constant	47.4283	53.05921	0.8939
LOG(Passenger trips)	0.256145	0.051875	4.9377
LOG(Vehicle Miles)	0.690993	0.058465	11.8189
LOG(Year)	-7.516339	6.982412	-1.0765
AVL	-0.050096	0.032915	-1.5220
AR(1)	0.80754	0.042432	19.0314
Adjusted R-squared			
Adjusted R-squared	0.988876		
S.E. of regression	0.118425		
Sum squared resid	2.678667		
Log likelihood	143.8107		
Durbin-Watson stat	2.143785		
F-statistic	3485.847		

The use of AVL is captured by the AVL dummy variable. In the bus fleet regression it has a negative coefficient indicating the use of AVL by the transit firm will result in fewer buses being used, given the number of vehicle miles and the number of passenger trips. This provides one source of the cost savings reported in Table 6.

In Table 8 the impact of the use of AVL on the amount of energy used (reported in BTUs) is examined. AVL should permit better planning and more efficiency vehicle utilization. Therefore, both utilization of the existing fleet and the prospect of reducing the size of the bus fleet are possible sources of cost savings.

In this model the amount of energy used is related to the amount of output, measured by the *number of vehicle miles*, the density of the system, measured by *passengers per vehicle mile* and the *average trip length* as well as the presence of AVL in the transit firm.

In the regression results reported in Table 8 the growth of energy use over time is captured by the *year* variable. It is not statistically significant, however. Vehicle miles has a significant affect on the amount of fuel used. The elasticity of energy use with respect to vehicle miles is 0.96; a 1 percent increase in vehicle miles leads to a .96 percent increase in BTUs. This is energy primarily used to power the vehicles but would also include energy used in maintenance and other non-vehicle activities. Density has a positive impact on energy use which is puzzling. One would expect that as density increases efficiency would rise and hence the sign would be negative. Since density is measured by passengers per vehicle mile, it could be that more stops are made. Without more detailed operational information it is difficult to speculate as to the cause of the positive sign.

Average trip length has a negative impact on fuel use. This is reasonable since there are economies of stage length just as in airlines. The elasticity of energy used with respect to average trip length is -0.22 meaning a 1 percent increase in average trip length leads to a .22 percent reduction in energy used. The bus variable captured the impact of the size of the bus fleet on energy used. One would expect this to be positive since the more buses in the fleet the more energy one would expect to use.

The impact of the use of AVL is again captured through a dummy variable. The sign is negative and the coefficient is somewhat small, -0.0023. This is only half of the value of the coefficient on the AVL dummy variable in the buses regression (Table 7). Therefore, AVL has a more sizable impact on the fleet size than on the amount of energy used. This implies fleet planning is a more significant consequence than reduced energy use arising from the use of AVL.

**Table 8**  
**Regression of Fuel Use with AVL**

Dependent Variable: <b>LOG(BTU)</b>			
Sample(adjusted): 2 198			
Sample: 197 obs			
Variable	Coefficient	Std. Error	t-Statistic
Constant	-20.6144	30.45828	-0.676808
LOG(Year)	2.262245	2.011815	1.12448
LOG(Vehicle Miles)	0.968129	0.040636	23.82442
LOG(Density)	0.315394	0.035222	8.95446
LOG(Average trip length)	-0.225729	0.039833	-5.666884
LOG(Buses)	0.069148	0.041553	1.664092
AVL	-0.002349	0.001052	-2.23289
AR(1)	0.854251	0.038108	22.41658
Adjusted R-squared			
	0.996883		
S.E. of regression			
	0.068222		
Sum squared resid			
	0.879648		
Log likelihood			
	253.4957		
Durbin-Watson stat			
	1.658625		
F-statistic			
	8954.905		

In Table 9 we report the model of hours of maintenance and the use of AVL. Our data set contained information on the number of hours worked for maintenance, non-vehicle maintenance, administration and other. Each of these categories was examined for the impact of AVL. The only statistically significant result were with vehicle maintenance and hours of vehicle operation. This is really not unsurprising given the results contained in Table 7 and Table 8.

In Table 9 the hours of maintenance was related to the number of vehicles and the usage of the vehicles, measured by the annual vehicle hours. The model is a log linear specification as the previous ones have been. The impact of fleet size measured by the *buses* variable indicates an elasticity of maintenance hours with respect to fleet size of 0.27; a 1 percent increase in the fleet increases annual maintenance hours by approximately .3 percent. The fleet usage has a much more significant impact on maintenance hours. The elasticity of maintenance hours with respect to vehicle hours is 0.95; a 1 percent increase in vehicle hours leads to a .95 percent increase in maintenance hours. Thus, there is almost a one to one relationship.<sup>25</sup> The impact of AVL is measured

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<sup>25</sup> This result would be highly dependant on the age of the fleet. Newer buses would require less maintenance.

by the AVL dummy variable. The sign is negative and the magnitude of the coefficient is comparable to that in the buses regression (Table 7). The results show that given fleet size and usage, the impact of AVL is to reduce the annual maintenance hours.

In Table 10 the same set of variables is used to measure the impact on vehicle operation hours. If AVL reduces the number of hours of maintenance and provides an opportunity to reduce fleet size, it should also have a negative impact on operating hours. An examination of Table 9 and Table 10 indicates similar impacts of control variables and the use of AVL.

**Table 9**  
**Regression of Hours of Maintenance with AVL**

Dependent Variable: <b>LOG(HRSMAIN)</b>			
Sample(adjusted): 2 198			
Included observations: 197 after adjusting endpoints			
Variable	Coefficient	Std. Error	t-Statistic
Constant	-1.735319	0.638436	-2.7181
LOG(Buses)	0.270946	0.077463	3.4977
LOG(Vehicle Hours)	0.947166	0.079431	11.9244
AVL	-0.058556	0.03773	-1.5520
AR(1)	0.77337	0.045716	16.9168
Adjusted R-squared			
Adjusted R-squared	0.989102		
S.E. of regression	0.137738		
Sum squared resid	3.642583		
Log likelihood	113.5344		
Durbin-Watson stat	1.935045		
F-statistic	4448.234		

As the fleet size increases the hours of operation rise by a relatively small amount; the elasticity of hours of operation with respect to fleet size is 0.22. The comparable elasticity for maintenance hours is 0.27. The lower value for operation hours reflects excess capacity, shift work and the peak nature of the demand in public transportation. A similar result is evident with respect to vehicle usage. The elasticity of hours of operation with respect to vehicle usage is 0.84 while the comparable elasticity for maintenance hours is 0.94.

The impact of AVL on hours of operation is also negative, as with the effect on hours of maintenance. The magnitude of the coefficient is comparable with a slightly smaller value for operation hours.

**Table 10**  
**Regression of Impact on Hours of Vehicle Operation by AVL**

Dependent Variable: <b>LOG(HRSVO)</b>			
Sample(adjusted): 2 198			
Included observations: 197 after adjusting endpoints			
Convergence achieved after 7 iterations			
Variable	Coefficient	Std. Error	t-Statistic
C	1.28092	0.404208	3.168963
LOG(Buses)	0.219198	0.048973	4.475895
LOG(Vehicle Hours)	0.841491	0.050365	16.70785
AVL	-0.046817	0.024802	-1.88763
AR(1)	0.641569	0.055247	11.61274
R-squared			
	0.994159		
Adjusted R-squared			
	0.994038		
S.E. of regression			
	0.090626		
Sum squared resid			
	1.576896		
Log likelihood			
	196.0021		
Durbin-Watson stat			
	2.183643		
F-statistic			
	8170.399		

These results are quite revealing. This is the first time the impact of AVL has been empirically investigated using productivity models. The exploration of the underlying drivers of productivity improvement has provided some indication of what strategies are most useful in reaping the benefits of AVL.

## 6 SUMMARY AND CONCLUSIONS

ITS has promised to improve the mobility and accessibility of people and goods in the economy. Over the past decade the United States and California in particular have invested heavily in the development of ITS technologies. Test beds and experiments have been used to examine the impact and to evaluate the feasibility of the technologies. Policy makers and public officials are now demanding some evidence that the 'new technologies' are going to deliver the benefits that have been promised and are going to meet the goals for which they were designed.

This research has focused on one particular ITS technology, Automatic Vehicle Location (AVL) applied to public transit.<sup>26</sup> This technology has emerged over the last twenty years from a relatively simple location information technology to one that can be used to provide information on passenger boardings, revenues and resource utilization. This rich variation in AVL usage provides a good opportunity to assess how well those transit firms that have adopted the technology have performed relative to those that have not.

We developed a data set incorporating information on 22 transit firms in different locations in the US. The transit firms were of comparable size. Some adopted AVL early in the period of assessment, 1987 through 1998 while others adopted it somewhat later. Some did not adopt AVL at all. The AVL technologies ranged from simple signpost indicators to GPS systems.

Our investigation explored three questions; did AVL have an impact on transit firm productivity; if productivity was affected did the impact differ across different AVL technologies and third, what were the drivers that underlay any productivity improvements, if any? The study used the concept of TFP to measure the productivity change and a series of second stage models to identify the separate contribution of AVL to the change in productivity. A dummy variable technique was used to identify the presence of AVL in a transit firm and the year it was introduced.

The study found that AVL has a positive impact on transit firm productivity when output is measured as revenue vehicle miles or passenger miles. In both cases, controlling for the environment in which the firm operated, the use of AVL led to an increase in productivity. We also tested for differences in the impact of different AVL technologies. There were no statistically significant differences across technologies. It may be that the data set is not rich enough to provide results in this matter.

Before exploring the cost drivers, the impact on passenger trips was examined. AVL can affect passenger demand since it can be used by transit firms to better inform the customers and schedule adherence and expected arrival times at a given transit stop. There is also the implicit affect that transit firms that have adopted AVL will likely have better schedule performance and this will show in higher passenger counts, given all other factors. The models showed that total passenger trips were higher on those transit firms that had adopted AVL. Both intertemporal and cross sectional variation supported this result.

The final set of models attempted to identify the underlying reasons for the change in productivity. Our reasoning was that it was not sufficient to simply identify that AVL leads to an improvement in productivity, although this is an important result for any benefit-cost assessment of AVL. We wanted to be able to point to underlying drivers to

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<sup>26</sup> This technology has become commonplace in the trucking industry for maximizing efficient usage of trucks and drivers.

assist transit managers in developing strategies to best exploit the opportunities provided by AVL.

The first model examined changes in cost efficiency. We found the cost per vehicle mile was lower when the transit firm used AVL. This was after controlling for output, capital and factor price effects. Following this we undertook a more micro-scale analysis to pinpoint which factors of operations were the source of any cost savings and how this might differ. Such information is valuable for rank ordering implementation strategies.

We found that the amount of bus capital, measured by fleet size, was smaller when AVL was utilized by the transit agency. In this model we controlled for both passenger trips and vehicle miles. This result was consistent with the idea that AVL allowed better scheduling and fleet planning and hence the same level of service could be provided with less capital. Following this we examined how the amount of energy used was affected by AVL. We found that total agency use of energy went down when AVL was adopted. The source of the lower energy usage came from both fewer buses and better utilization of the buses that were used.

The final set of models examined the impact of AVL on hours used for vehicle maintenance and hours of vehicle operations. We found AVL did not have an impact on hours in general administration or non-vehicle hours worked. We did find that AVL led to fewer hours of vehicle maintenance and to fewer hours of vehicle operation. The impact on maintenance hours was larger than on operation hours.

The overall assessment of AVL is that it provides sizable benefits for both consumers and transit agencies. Our work focused on the cost efficiency improvements from AVL but we were able to explore some demand side benefits as well. We found higher numbers of passenger trips when AVL was used by the transit agency. The most significant contributions were in improving productivity and cost efficiency. Whether we measured output as passenger oriented or service oriented, factor productivity was greater with the use of AVL. The sources of the productivity gains came from better use of capital, the need for fewer buses, the more efficient use of fuel and energy generally, and the reduction in the amount of labor needed for both vehicle maintenance and vehicle operations.

This study is the first attempt to provide such measures using economic productivity models. It is also the first piece of work to link the sources of the productivity gains to specific factor and operational strategies. All in all it appears AVL is delivering the benefits it had promised.

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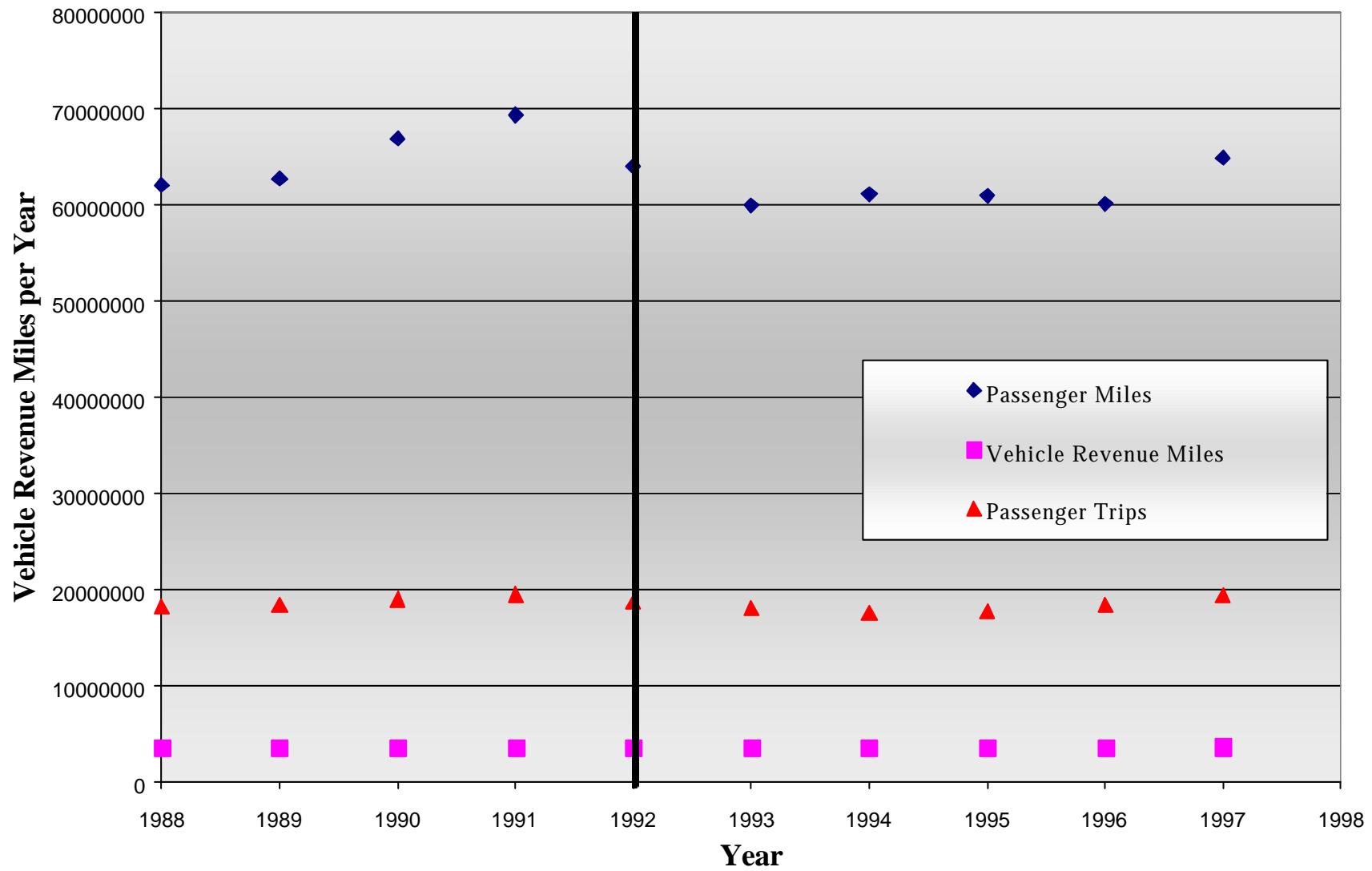
US Department of Transportation, *Advanced Public Transportation Systems: Evaluation Guidelines*, January 1994 (Office of Technical Assistance and Safety) DOT-T-94-10



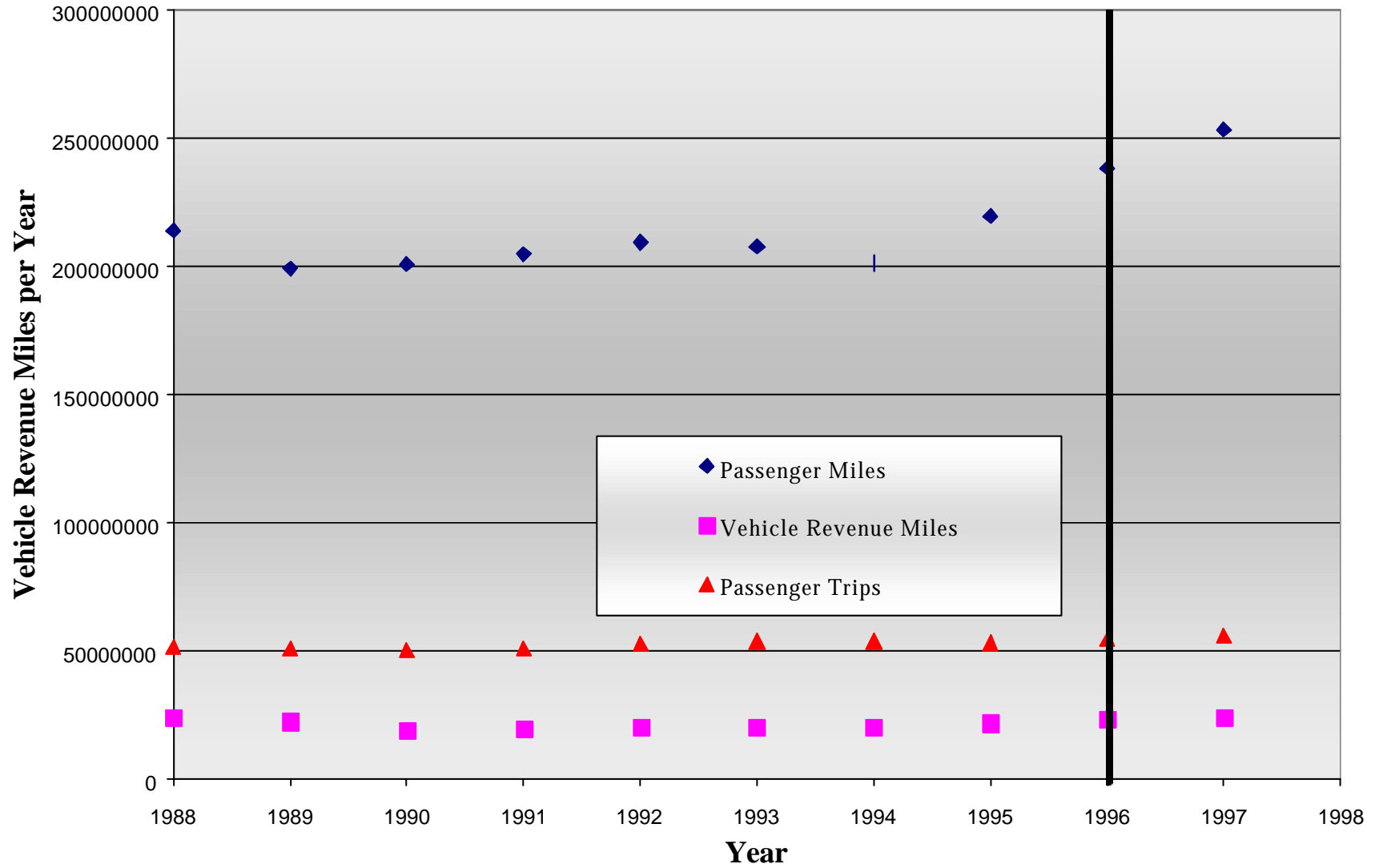
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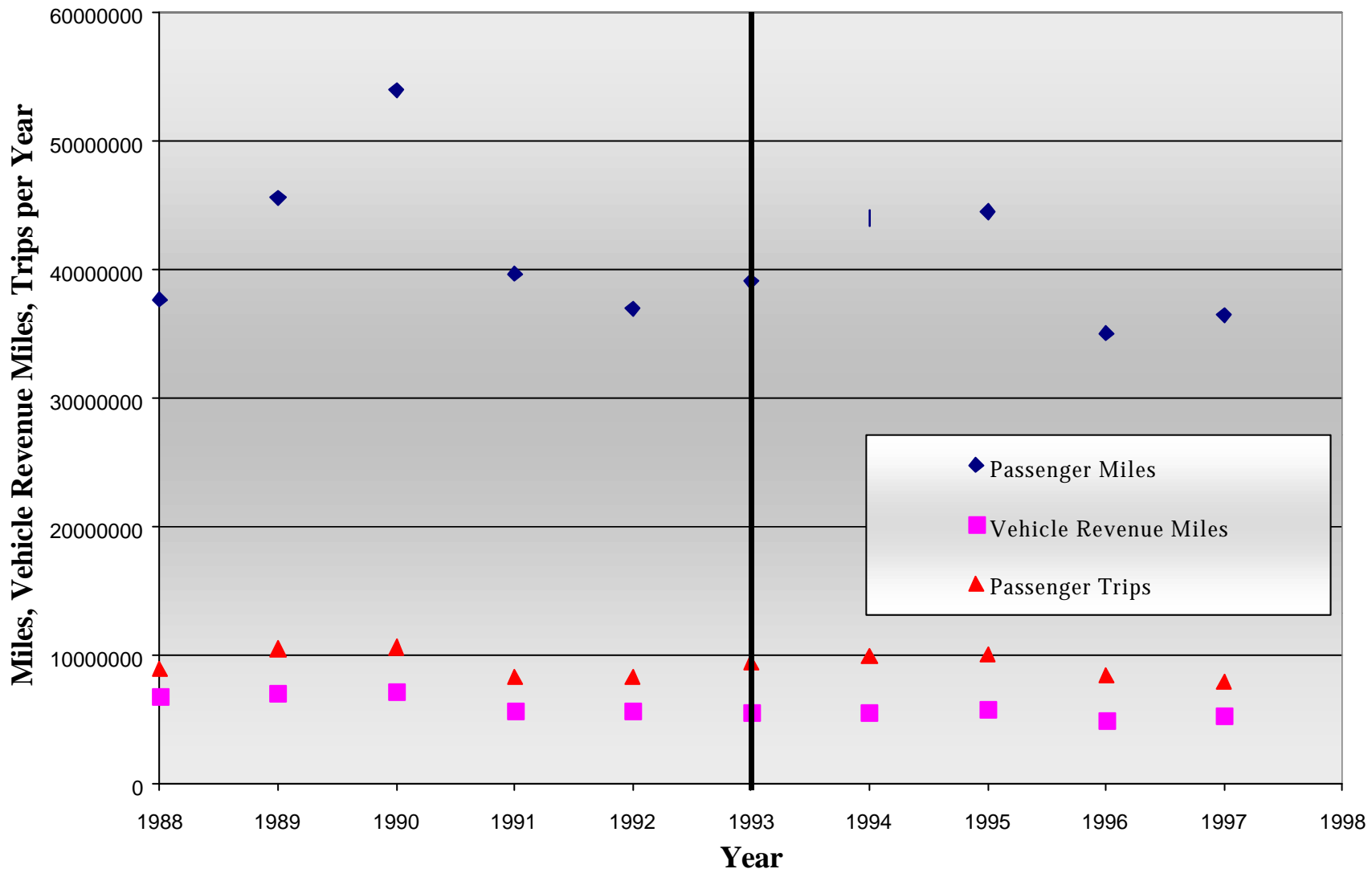
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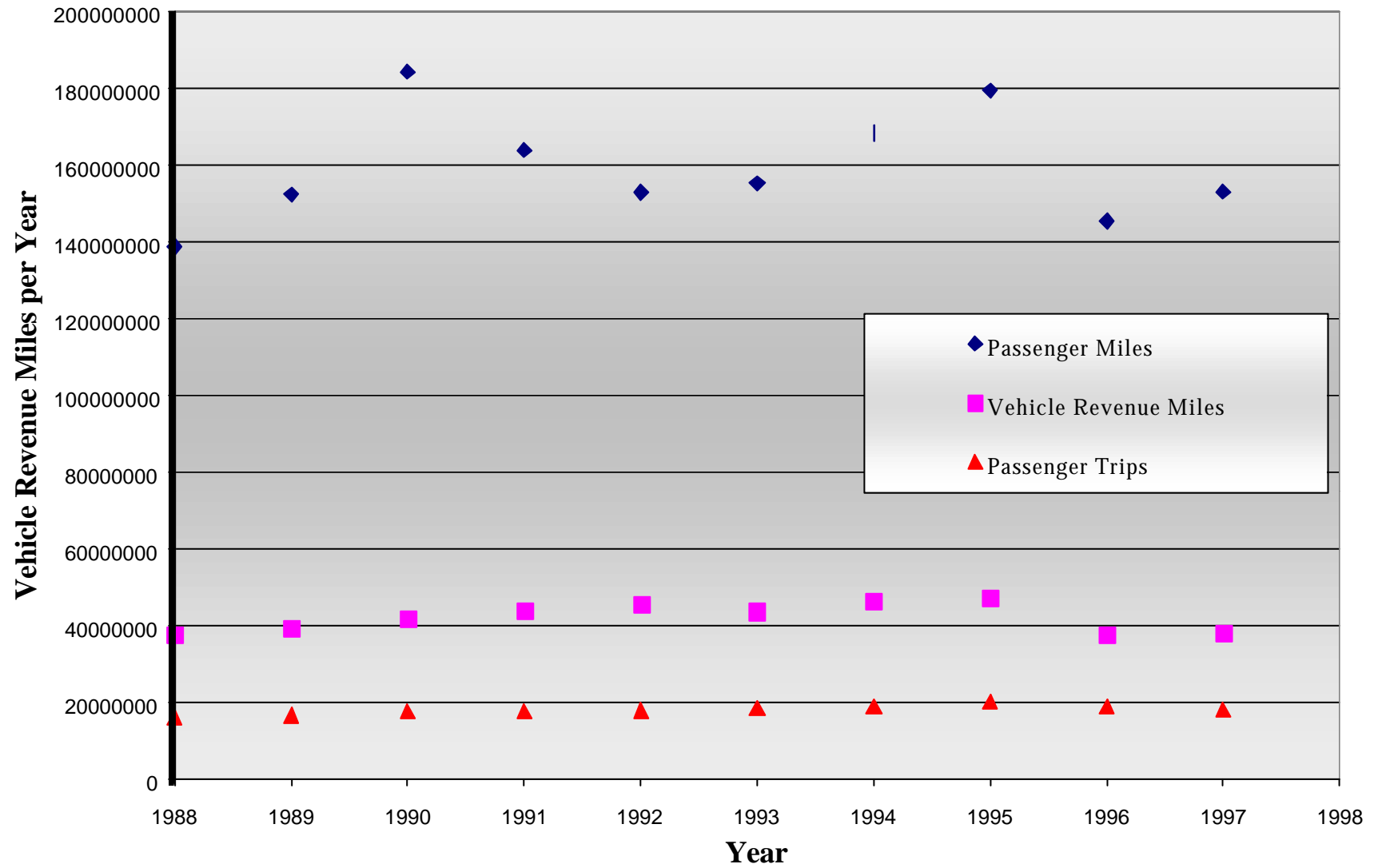
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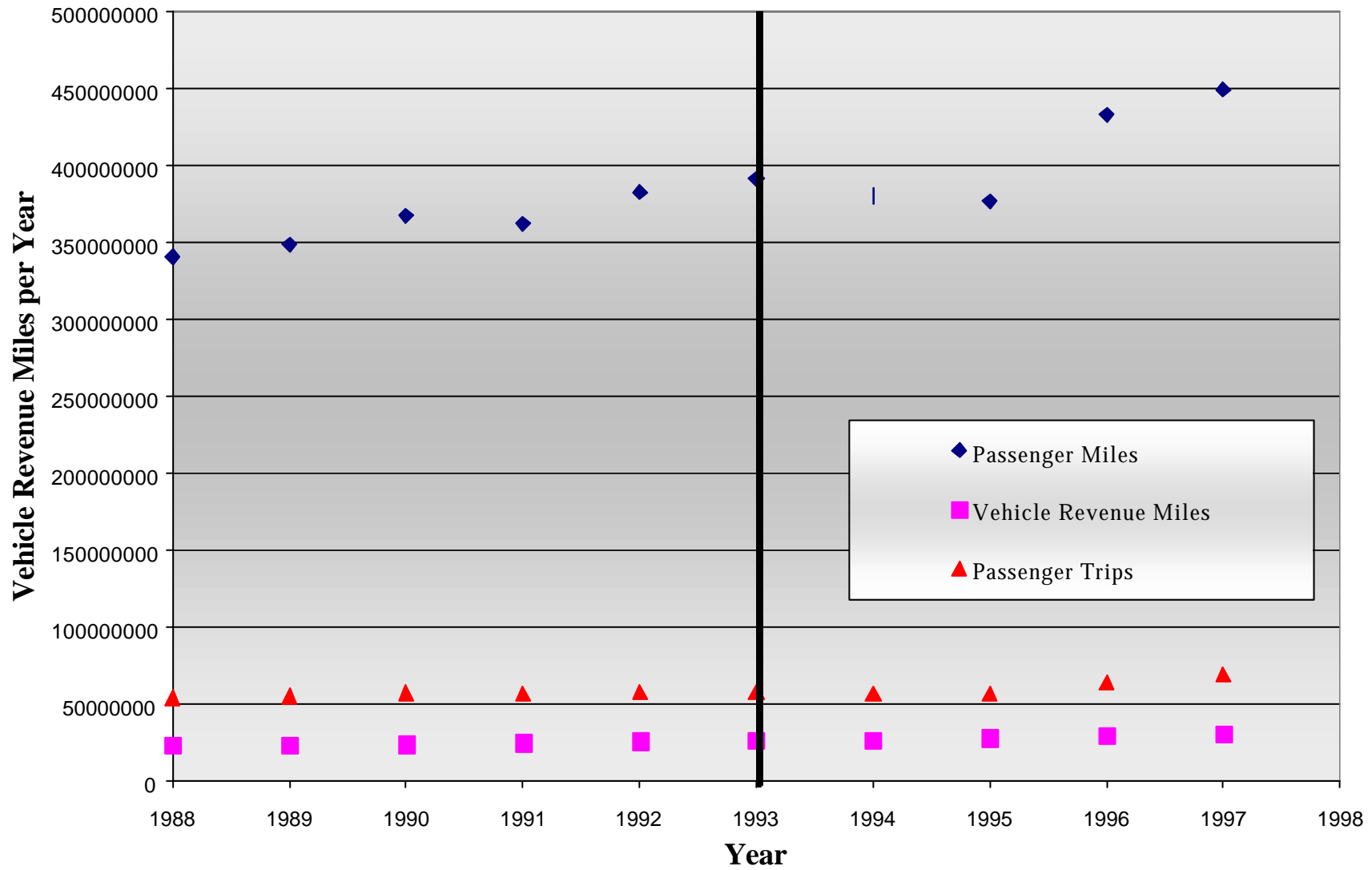
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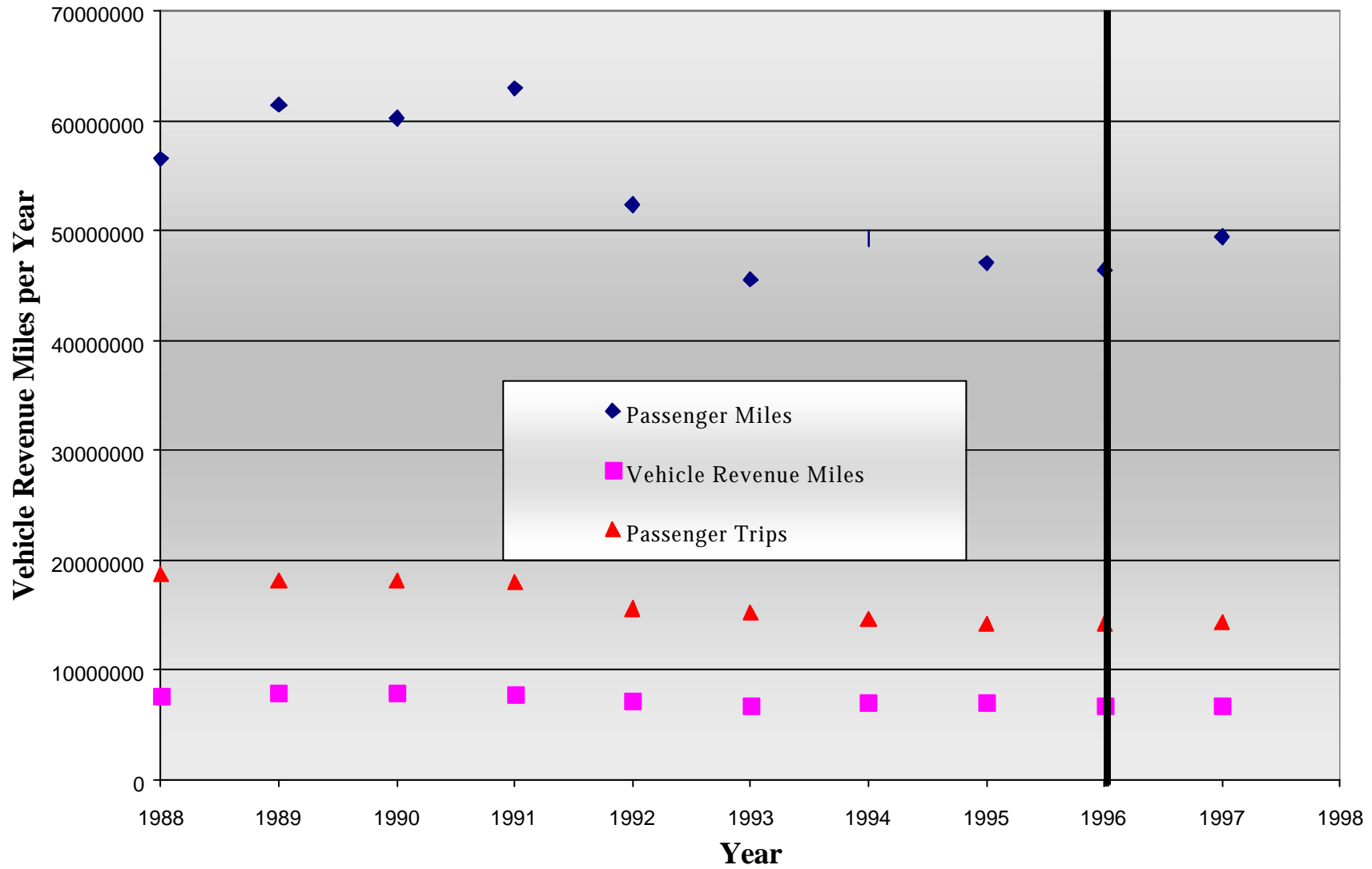
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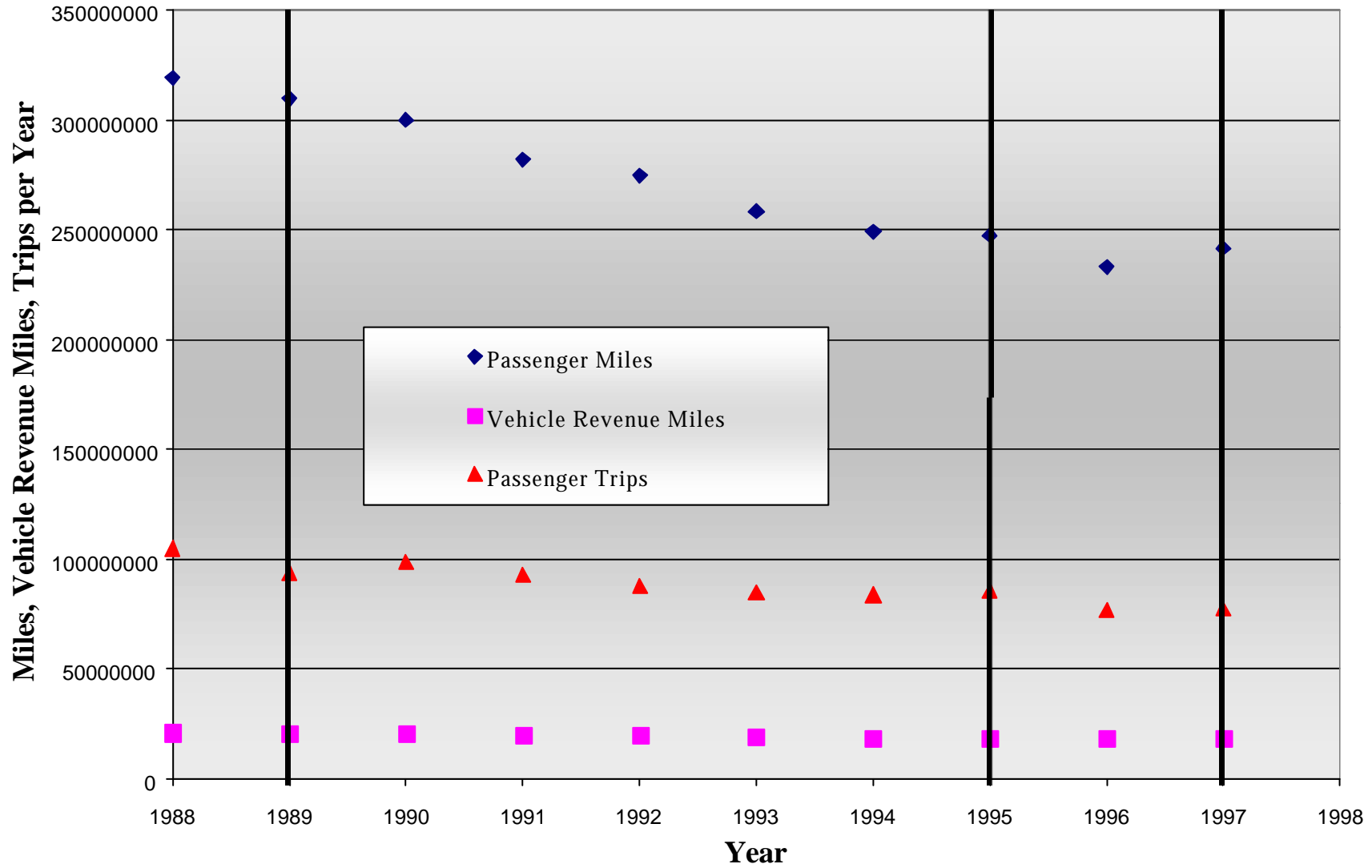
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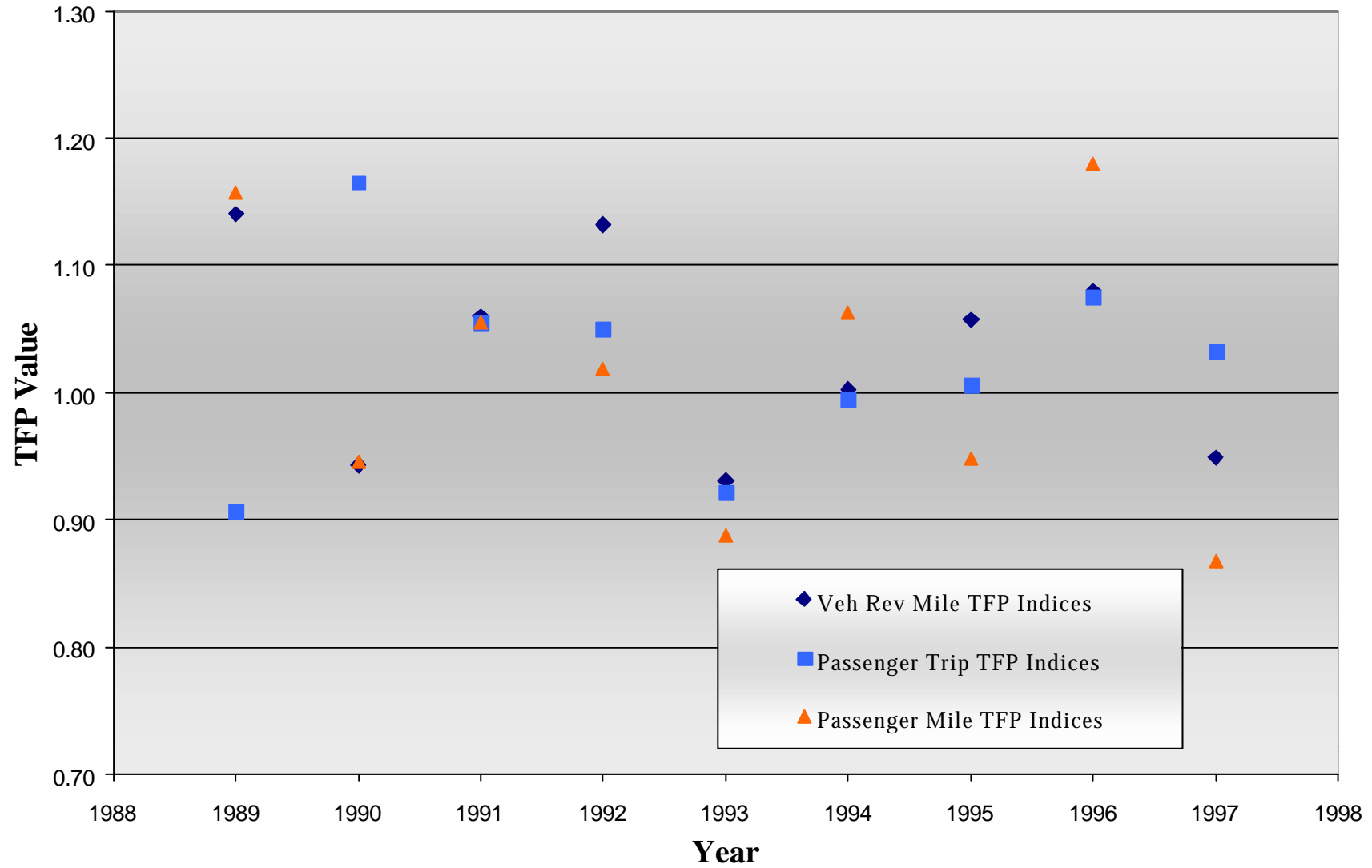


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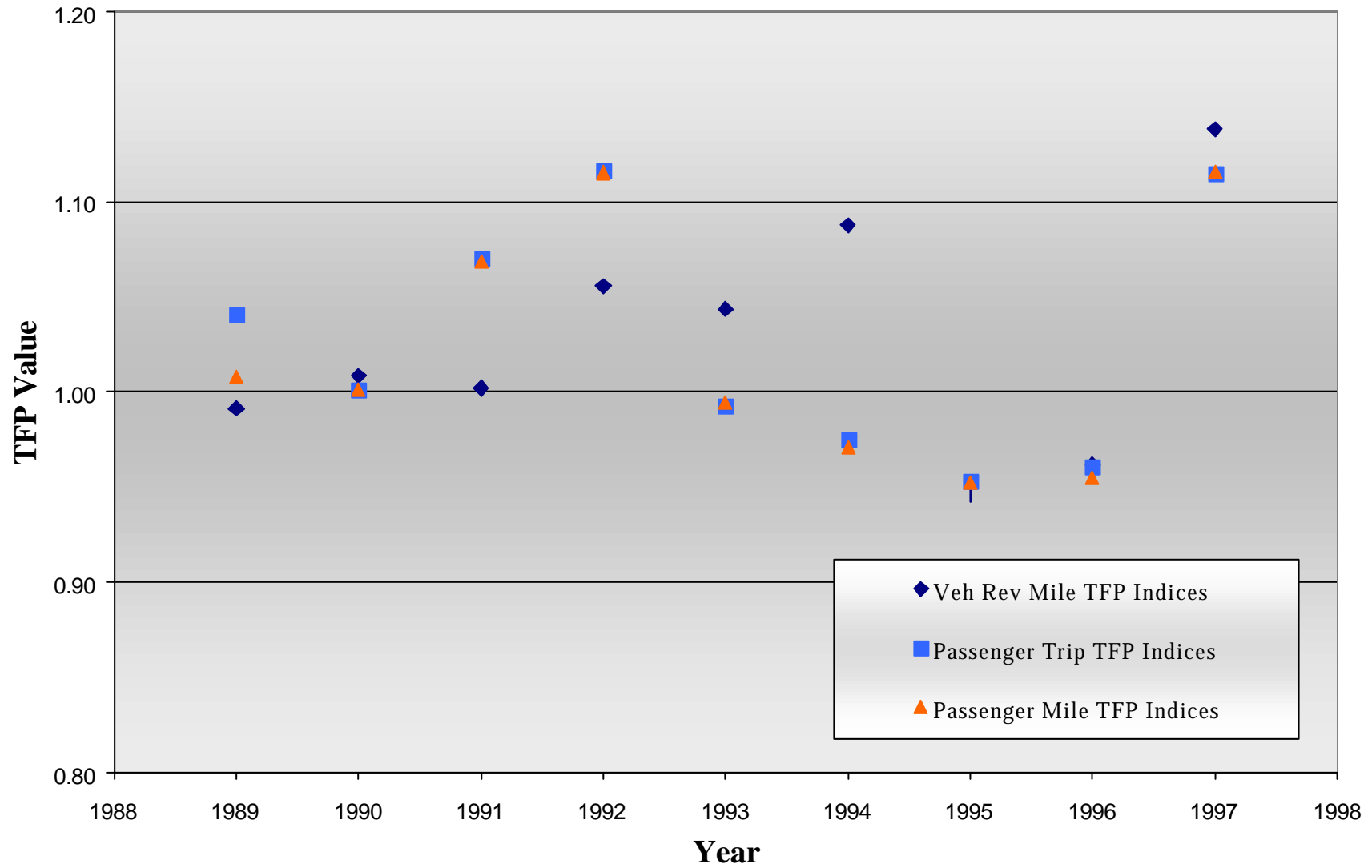




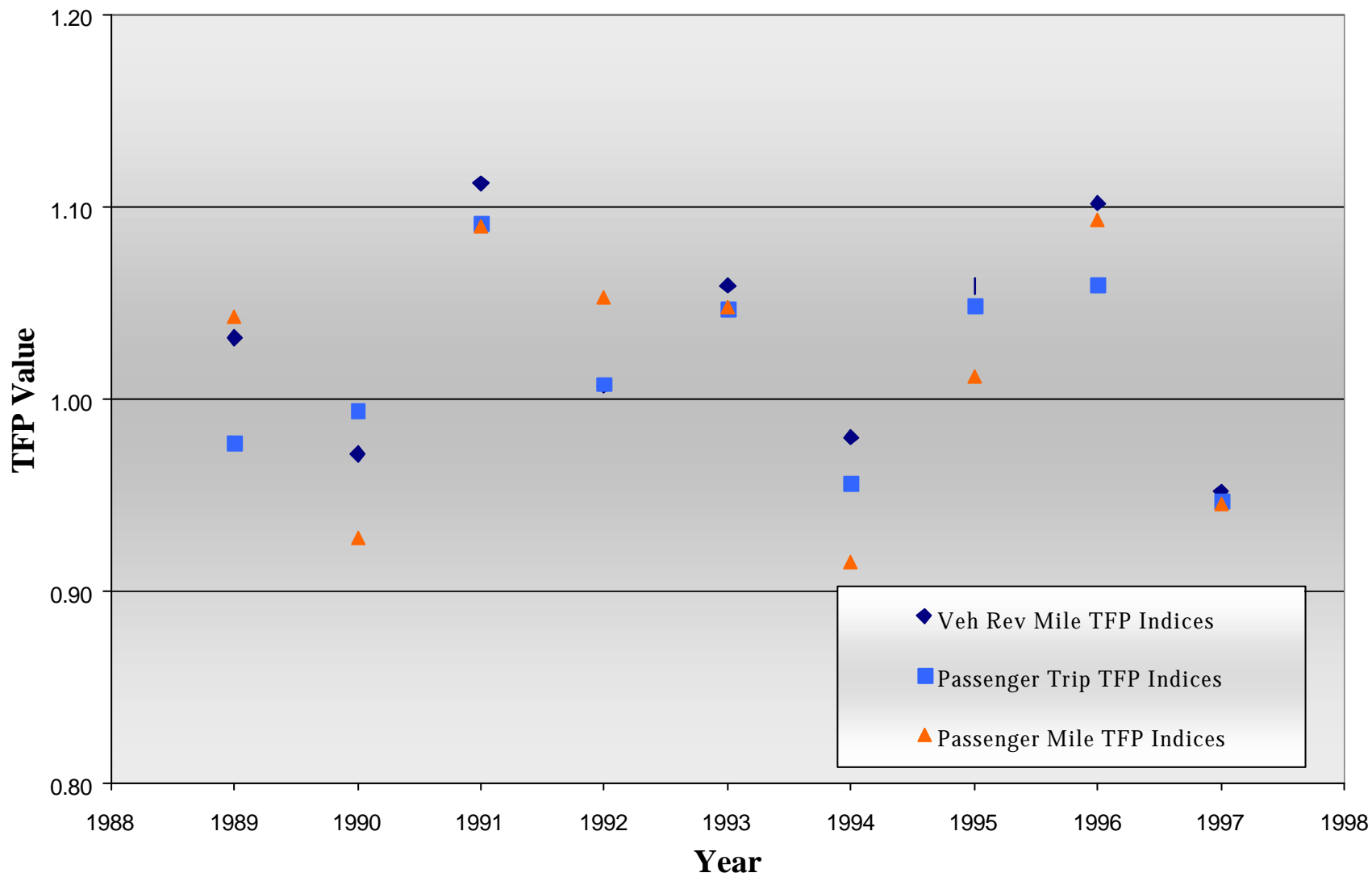
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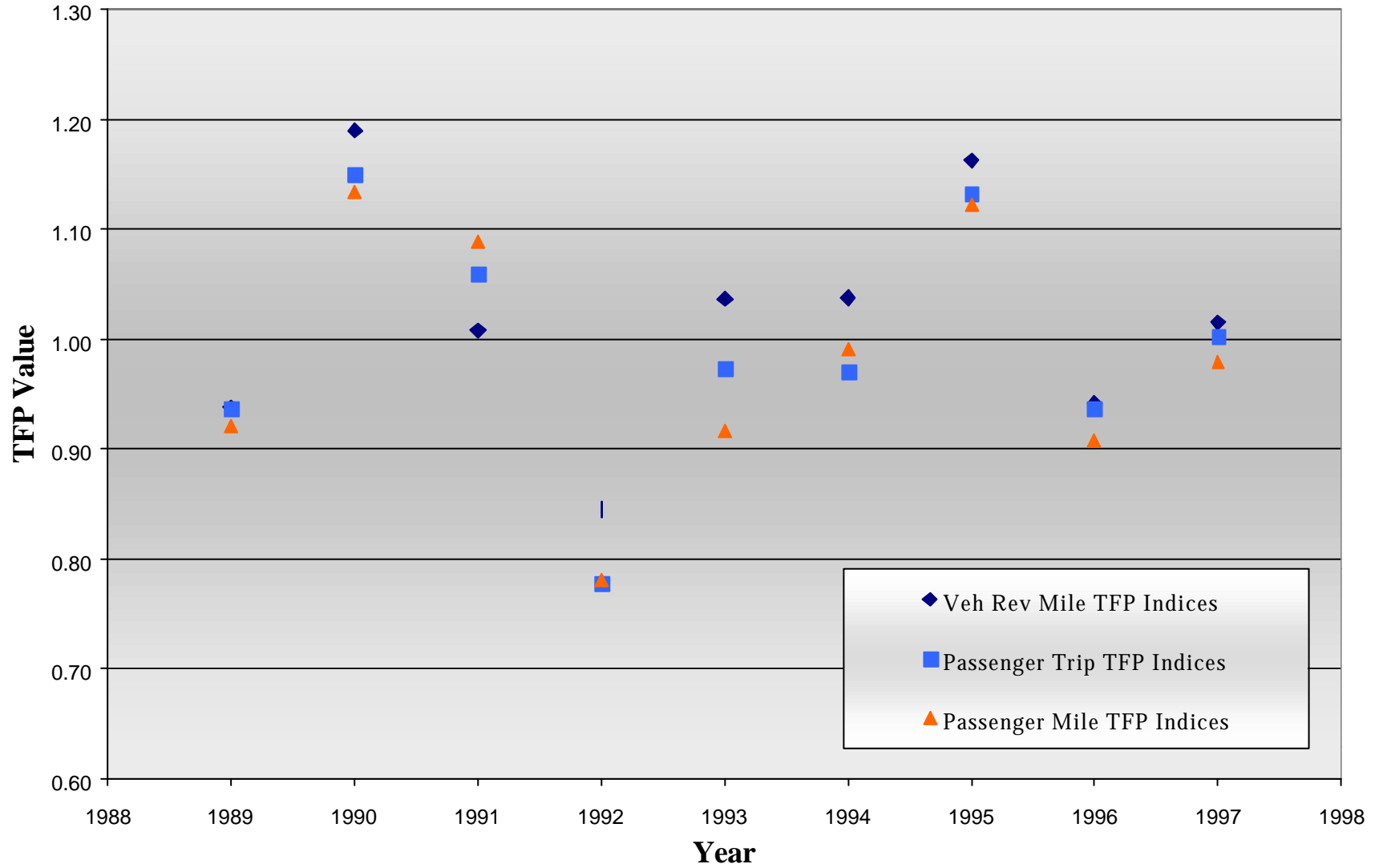
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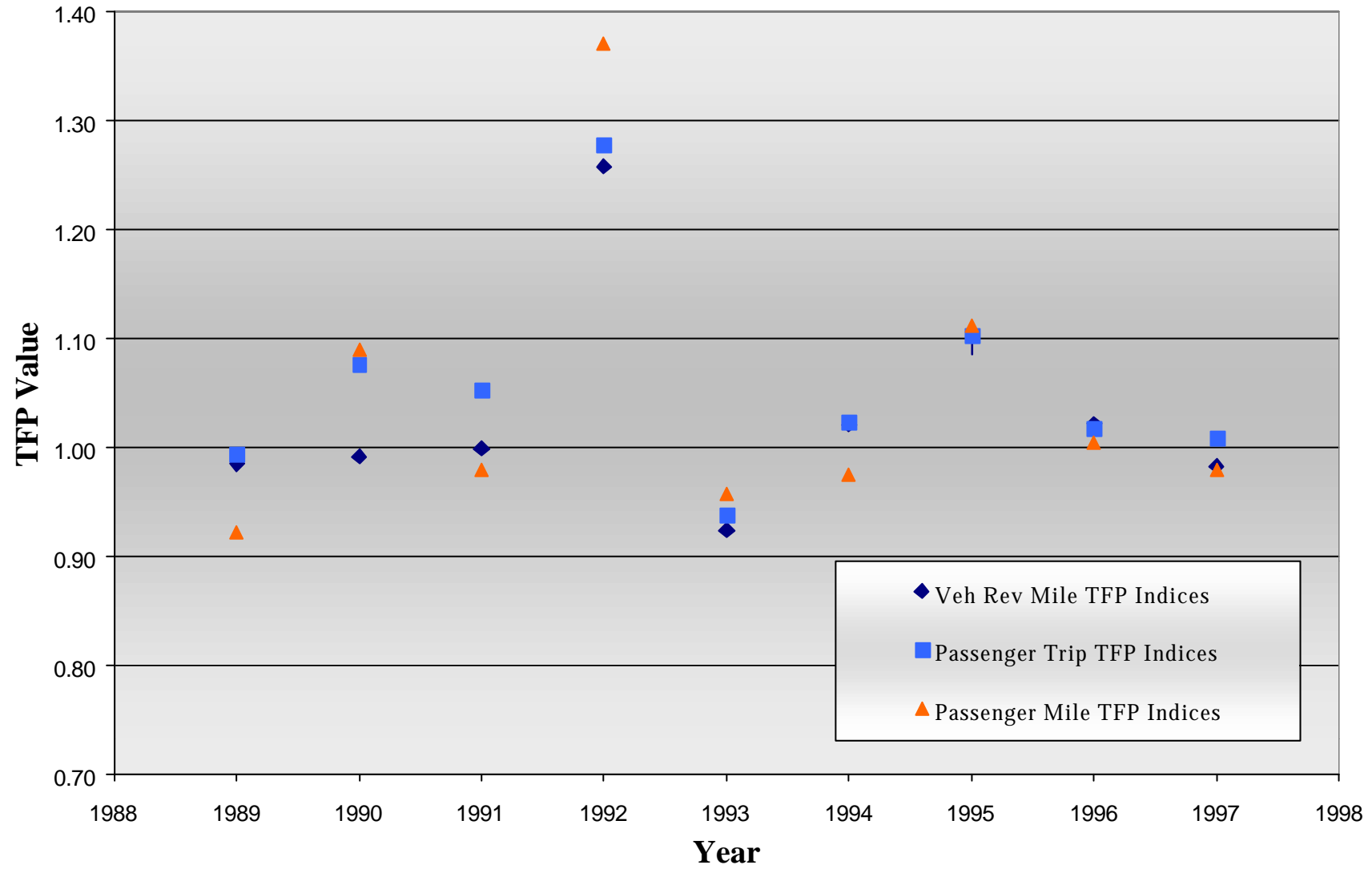
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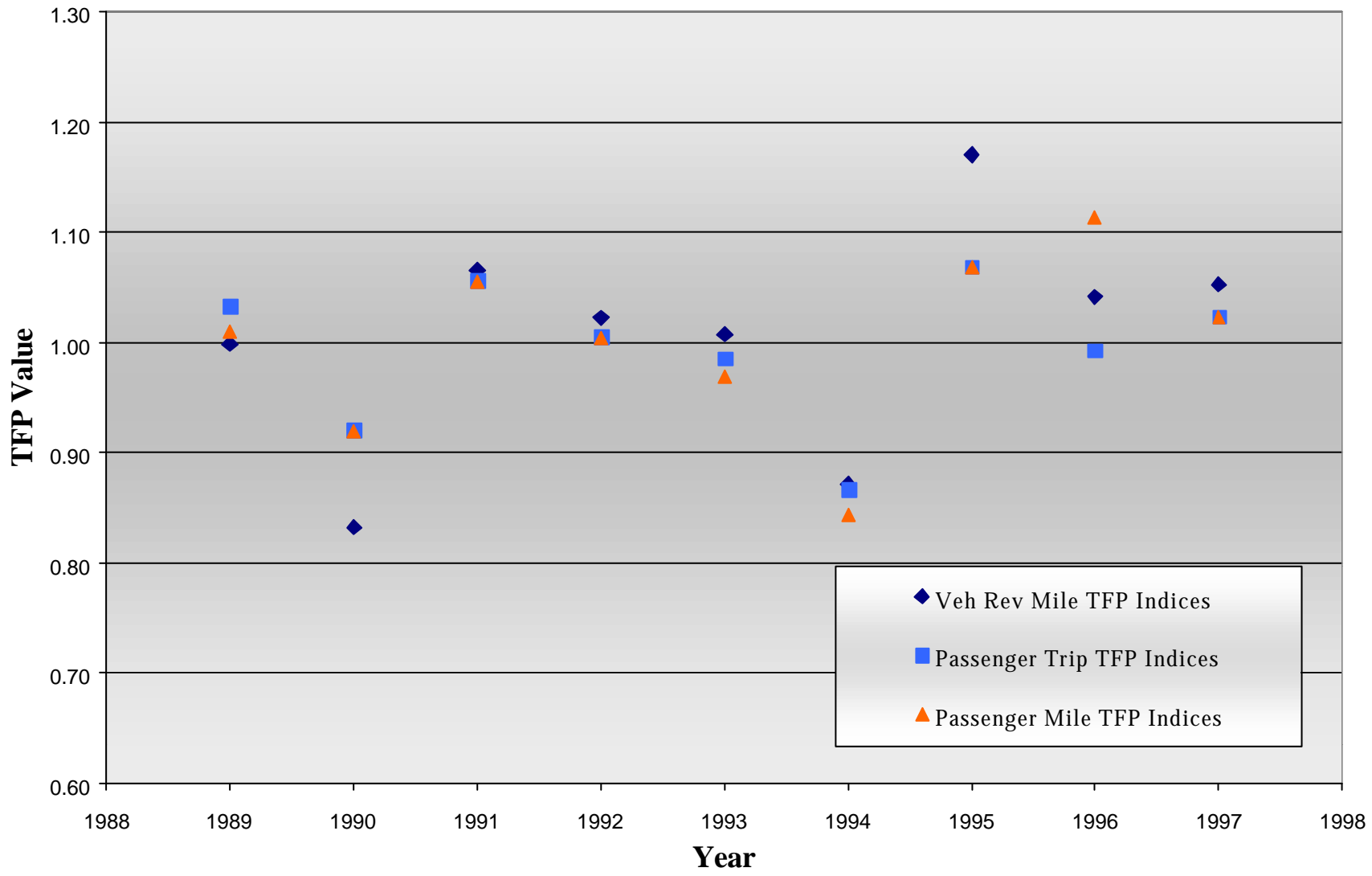
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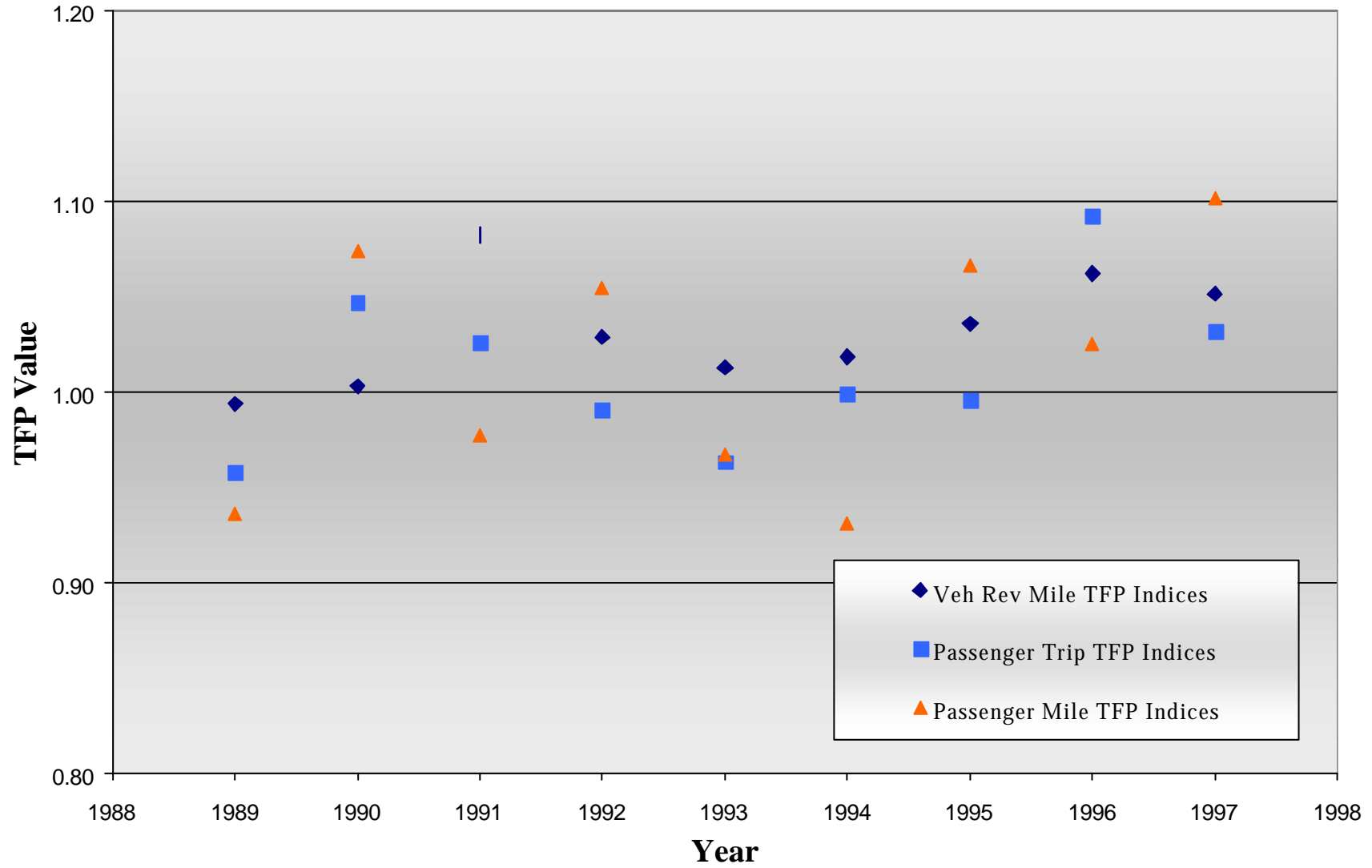
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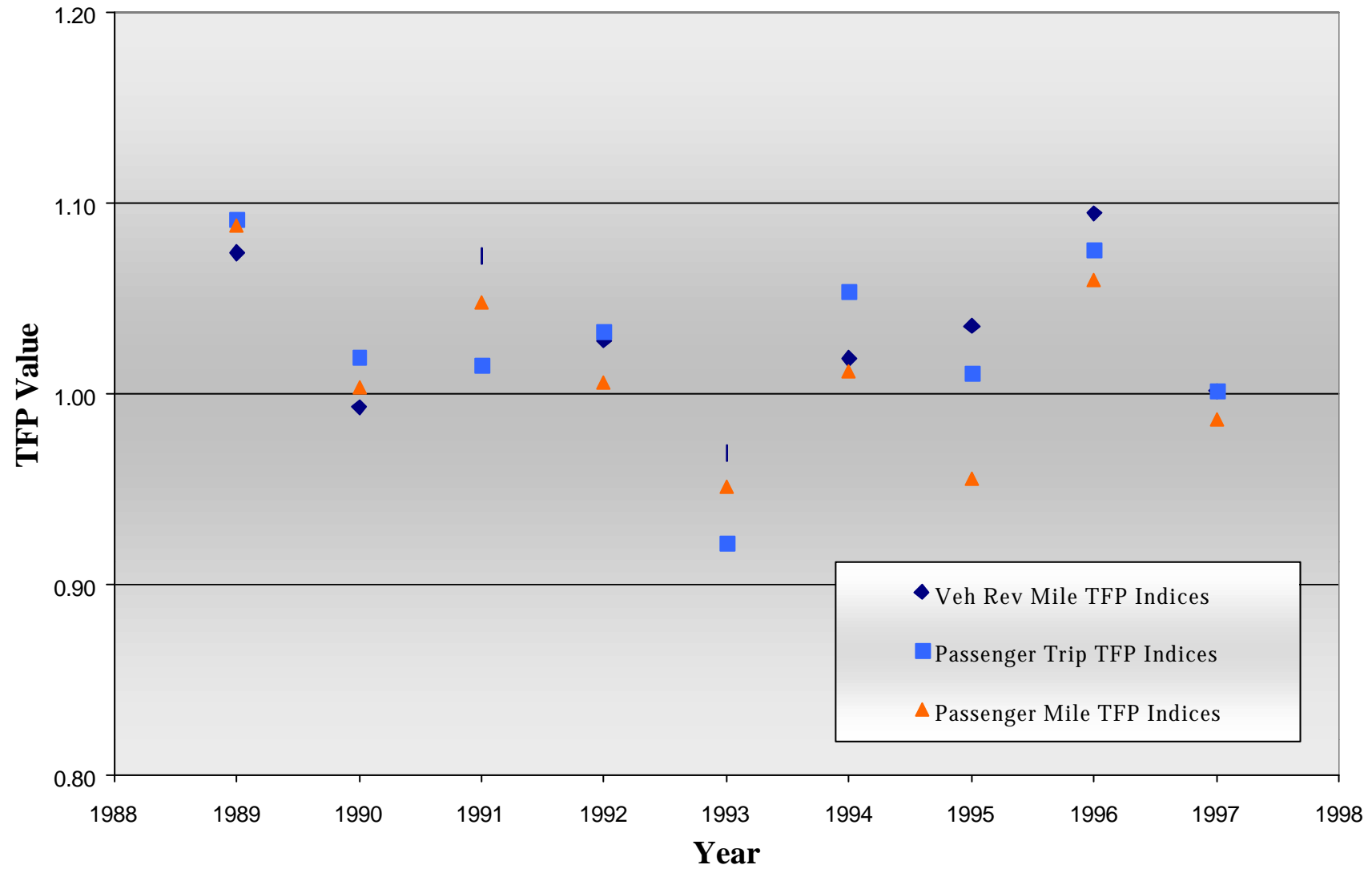
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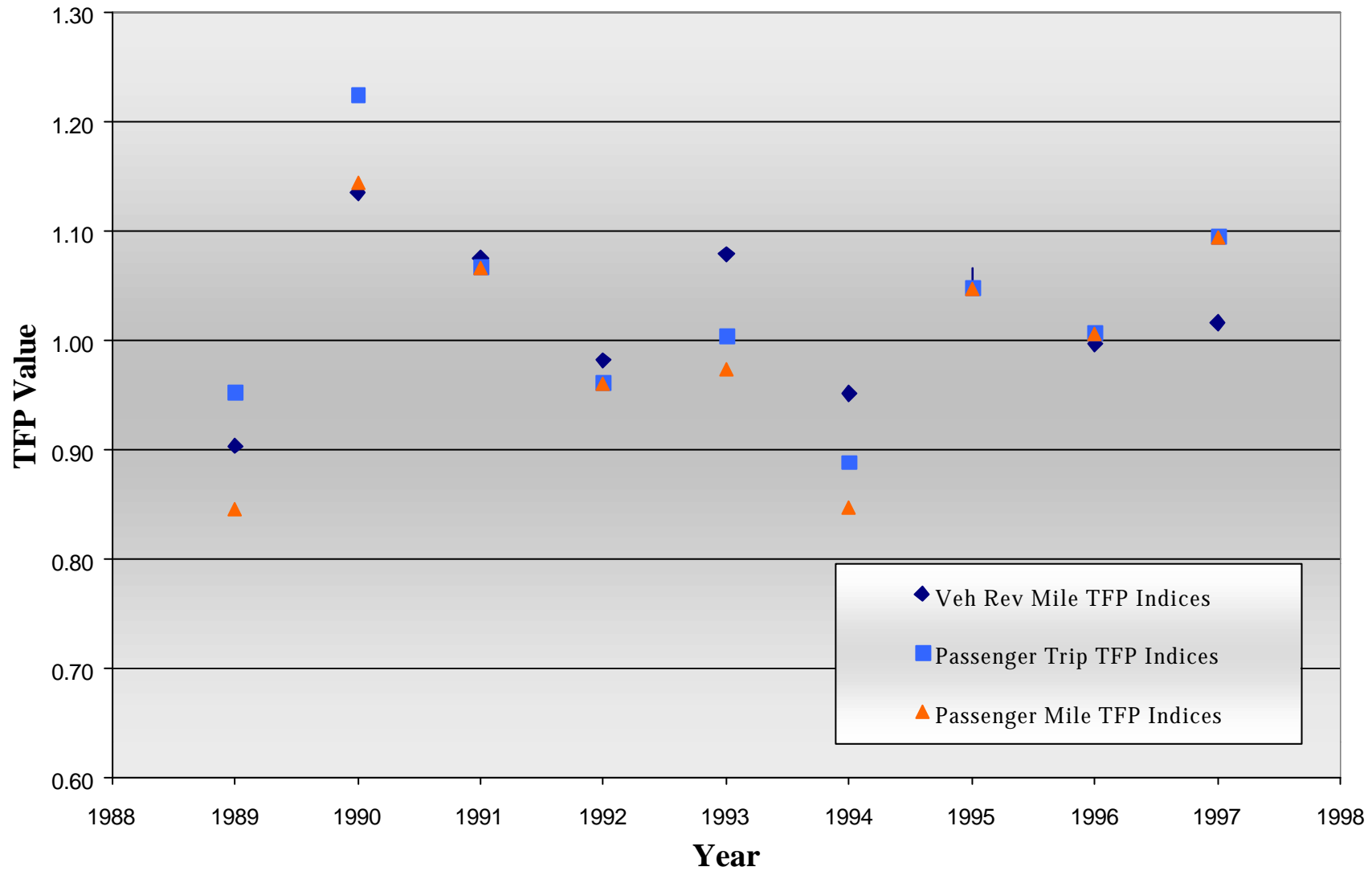


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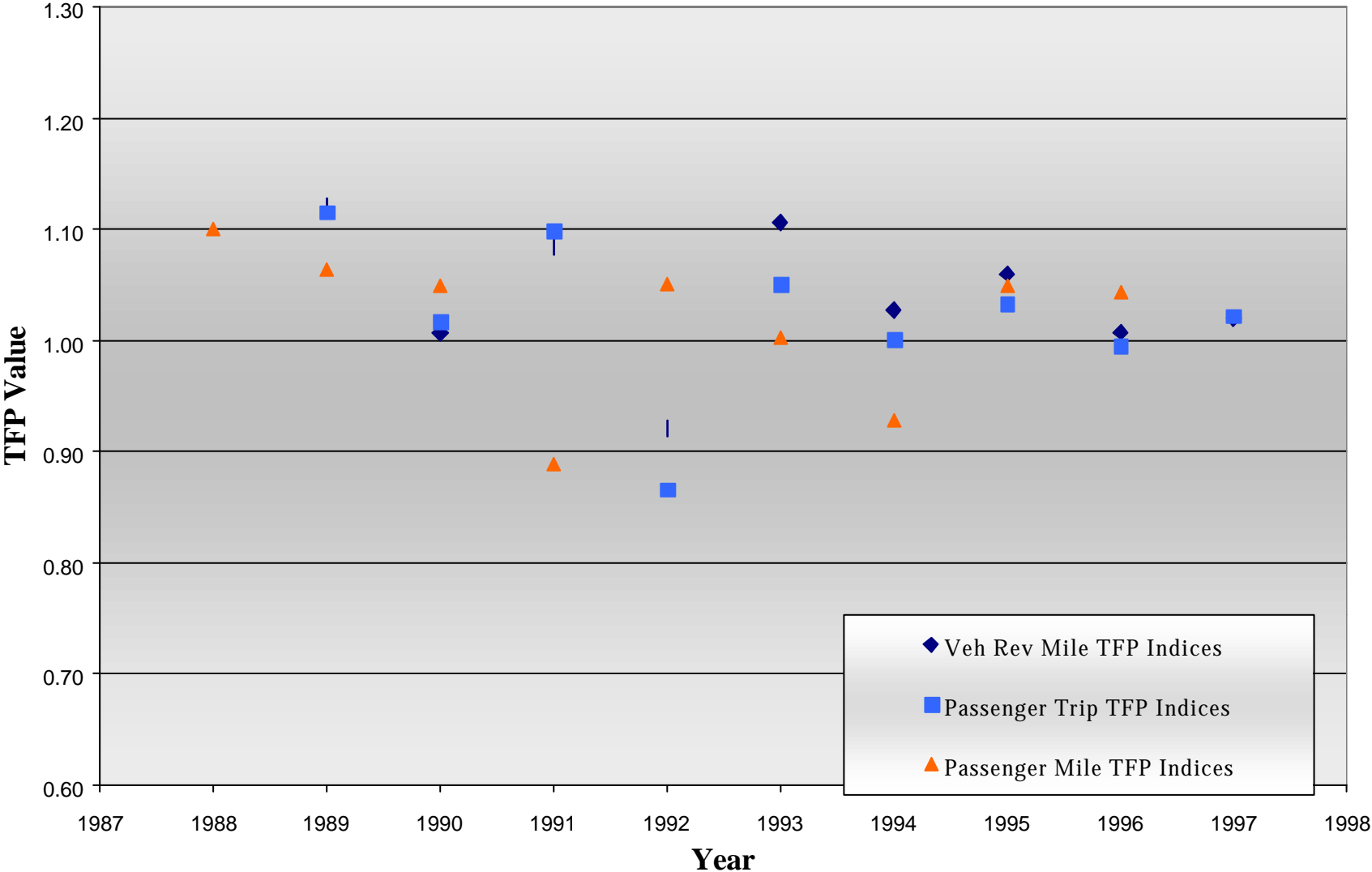




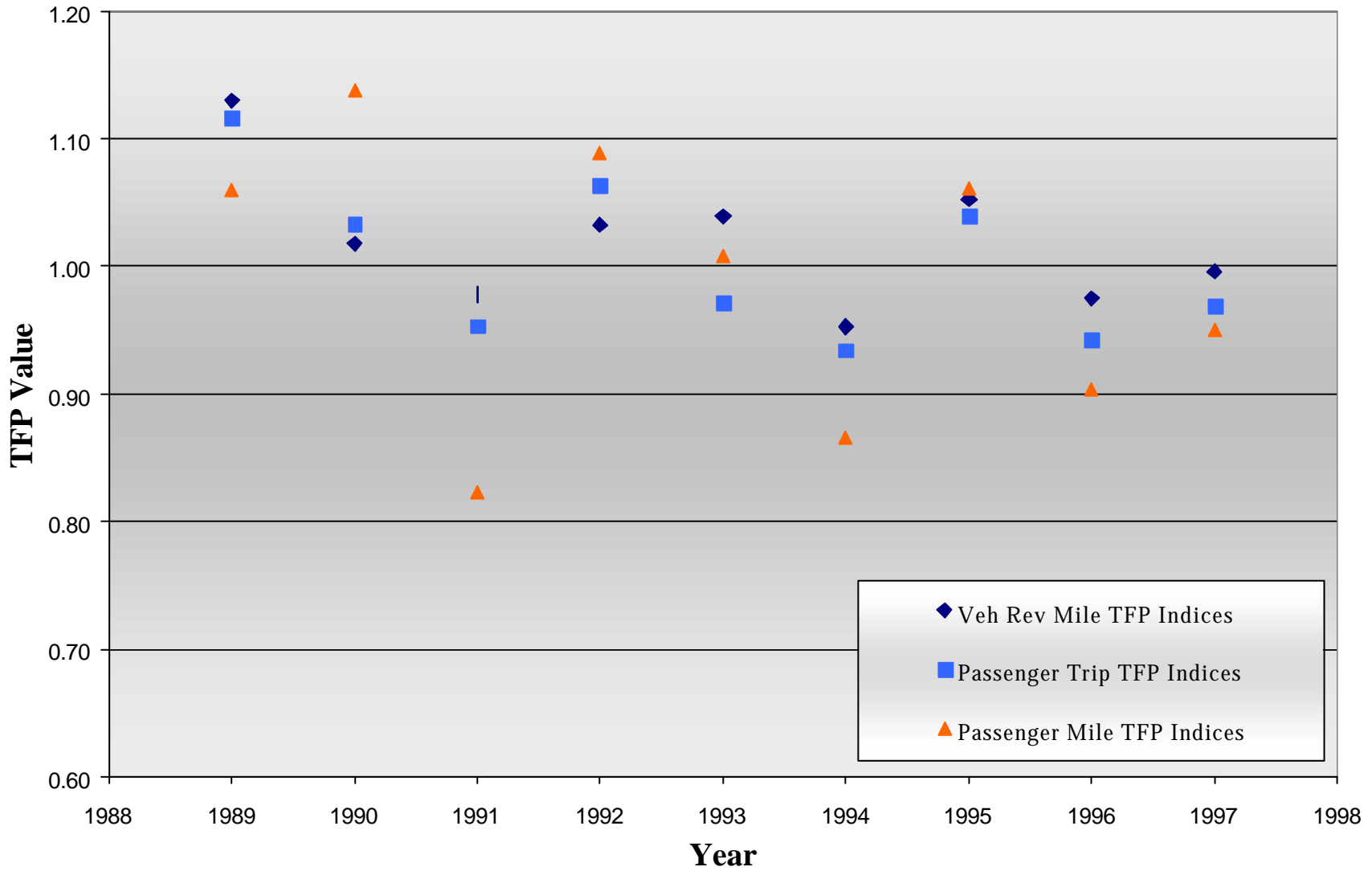
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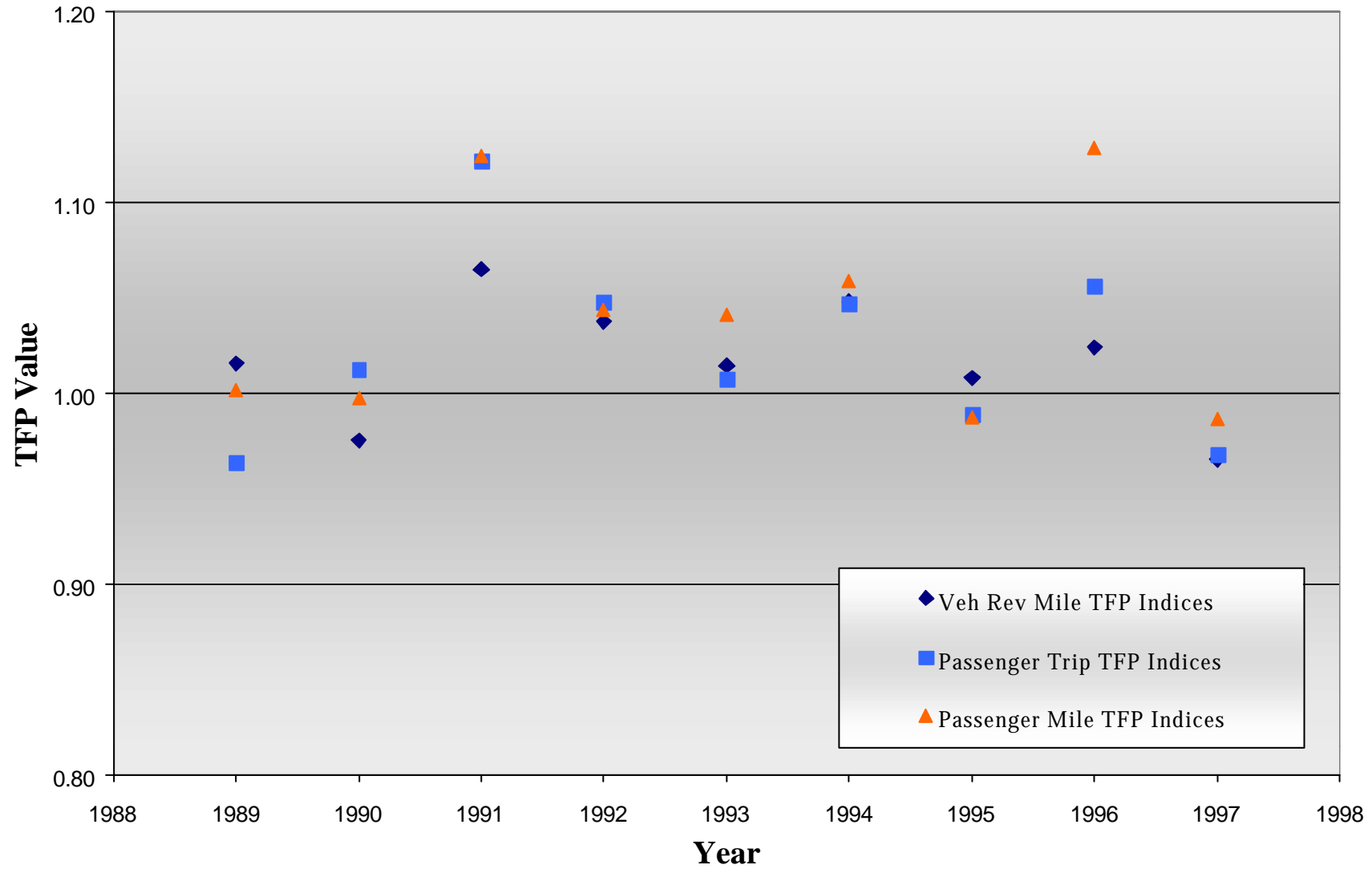
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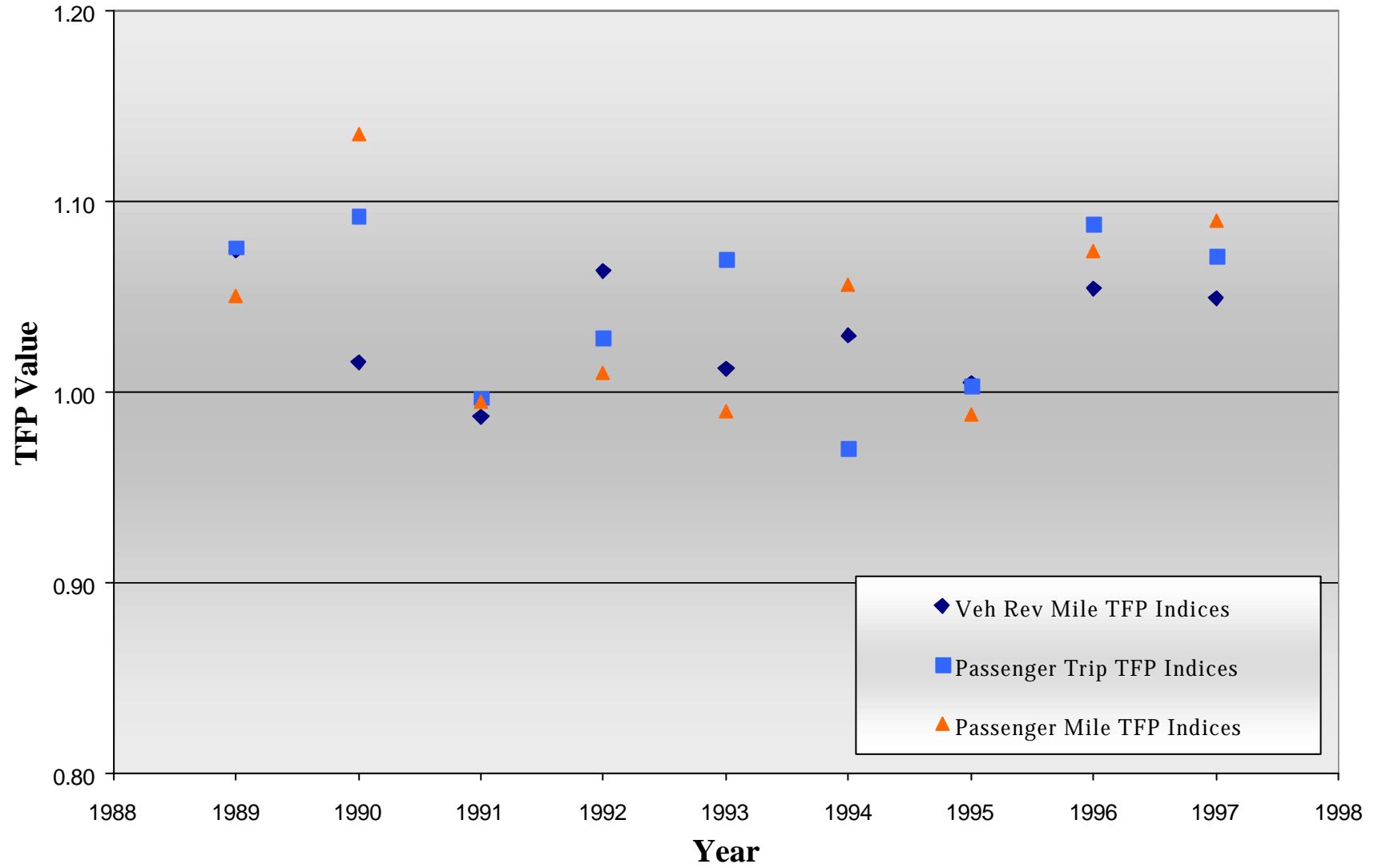
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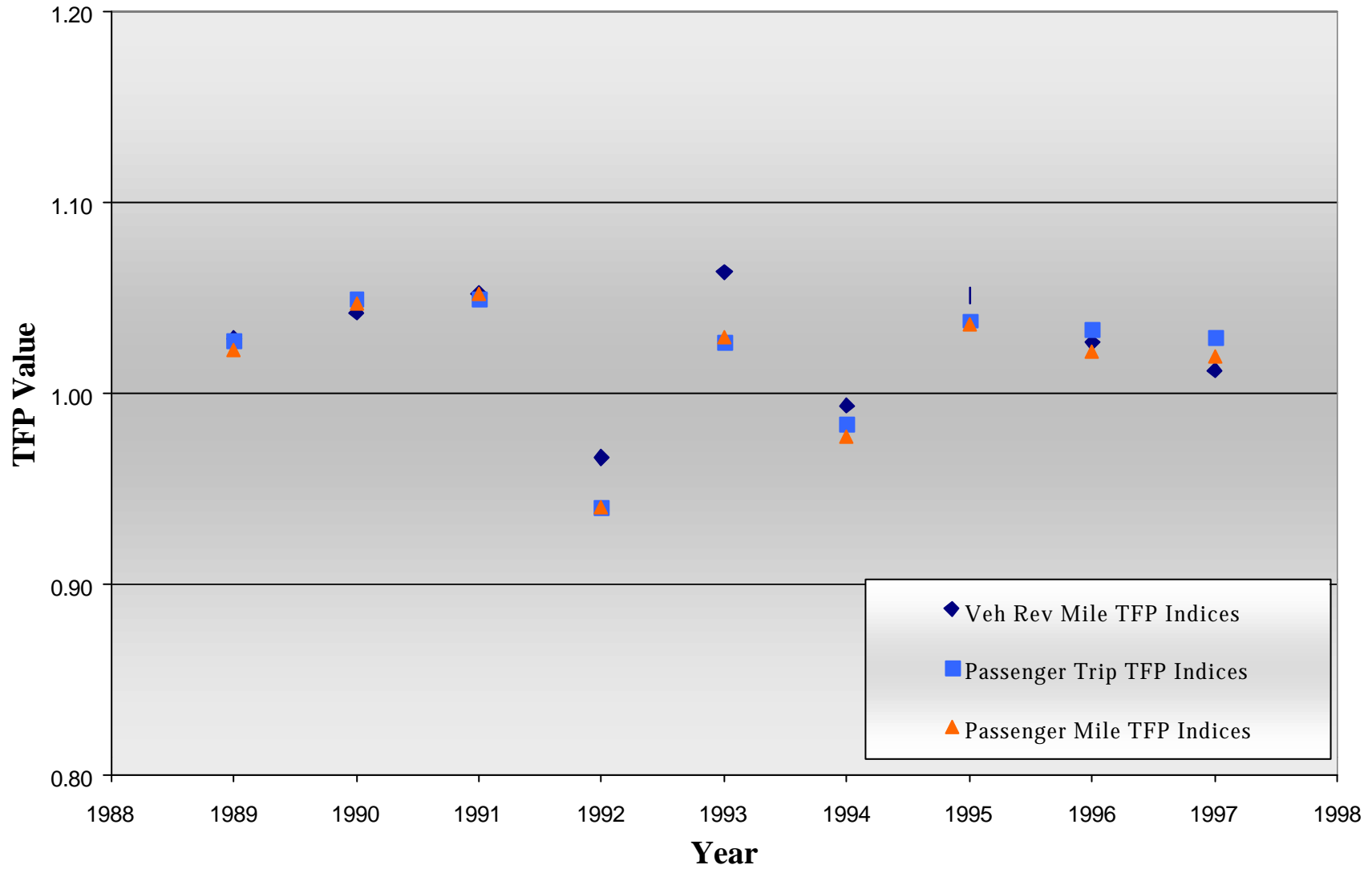
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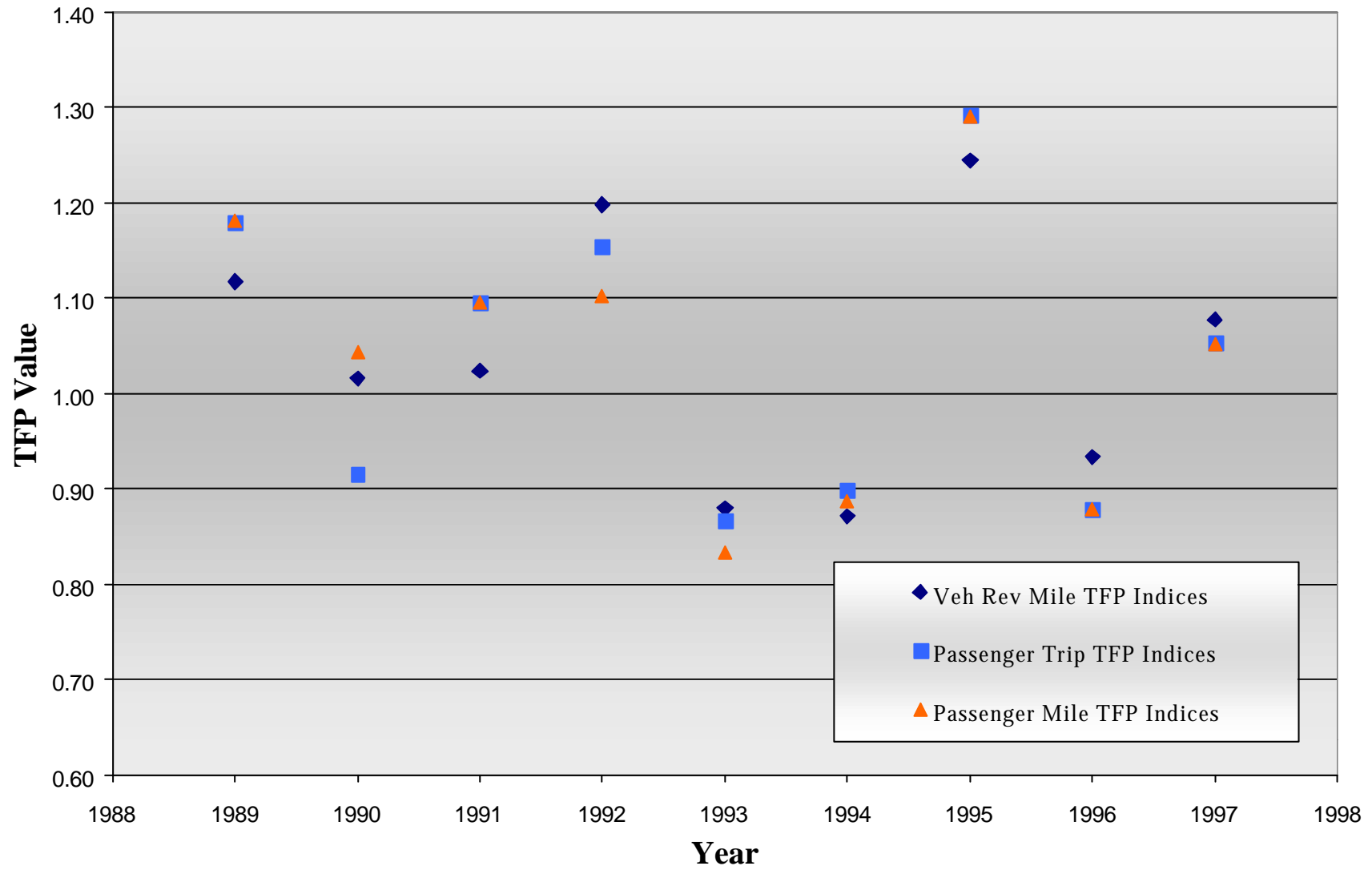


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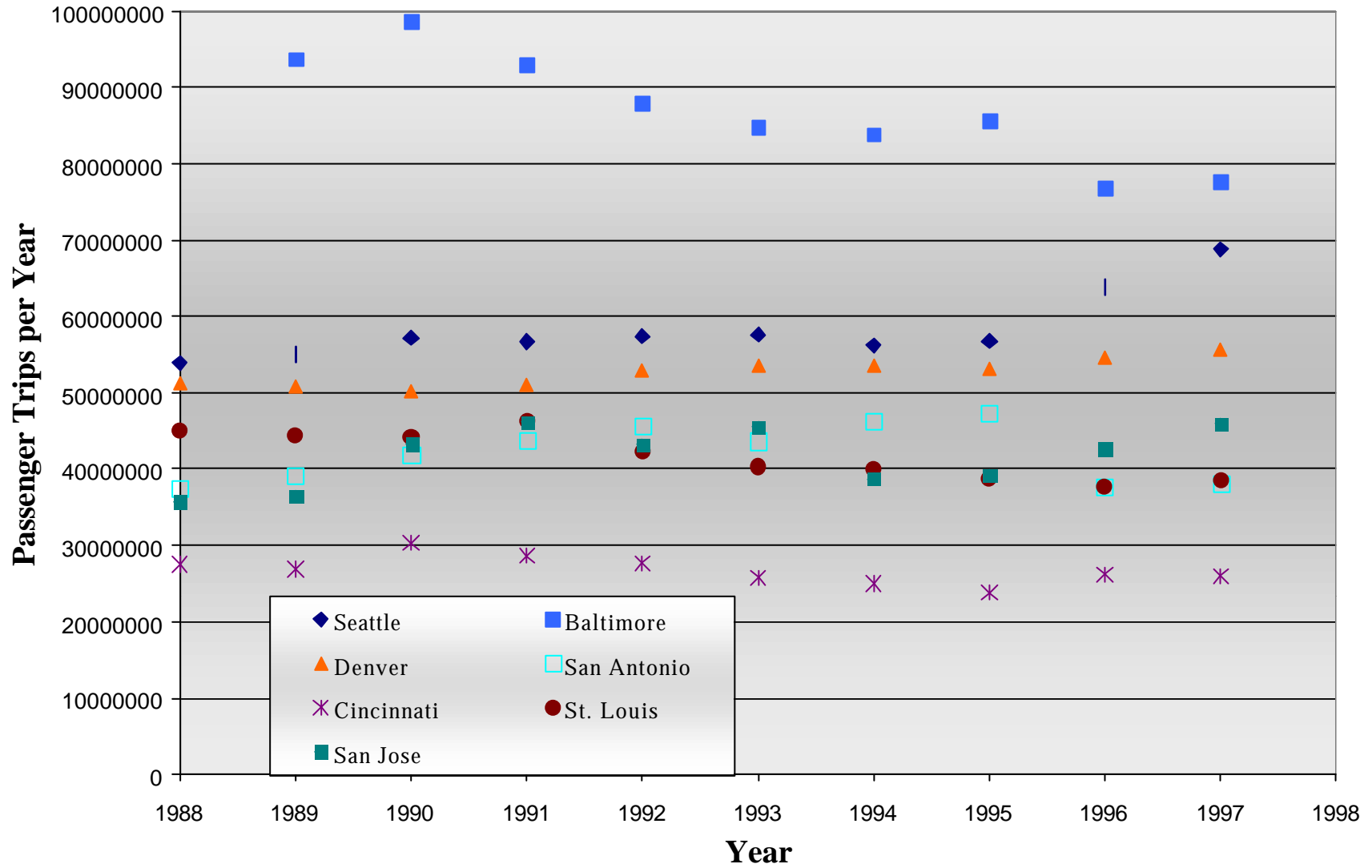


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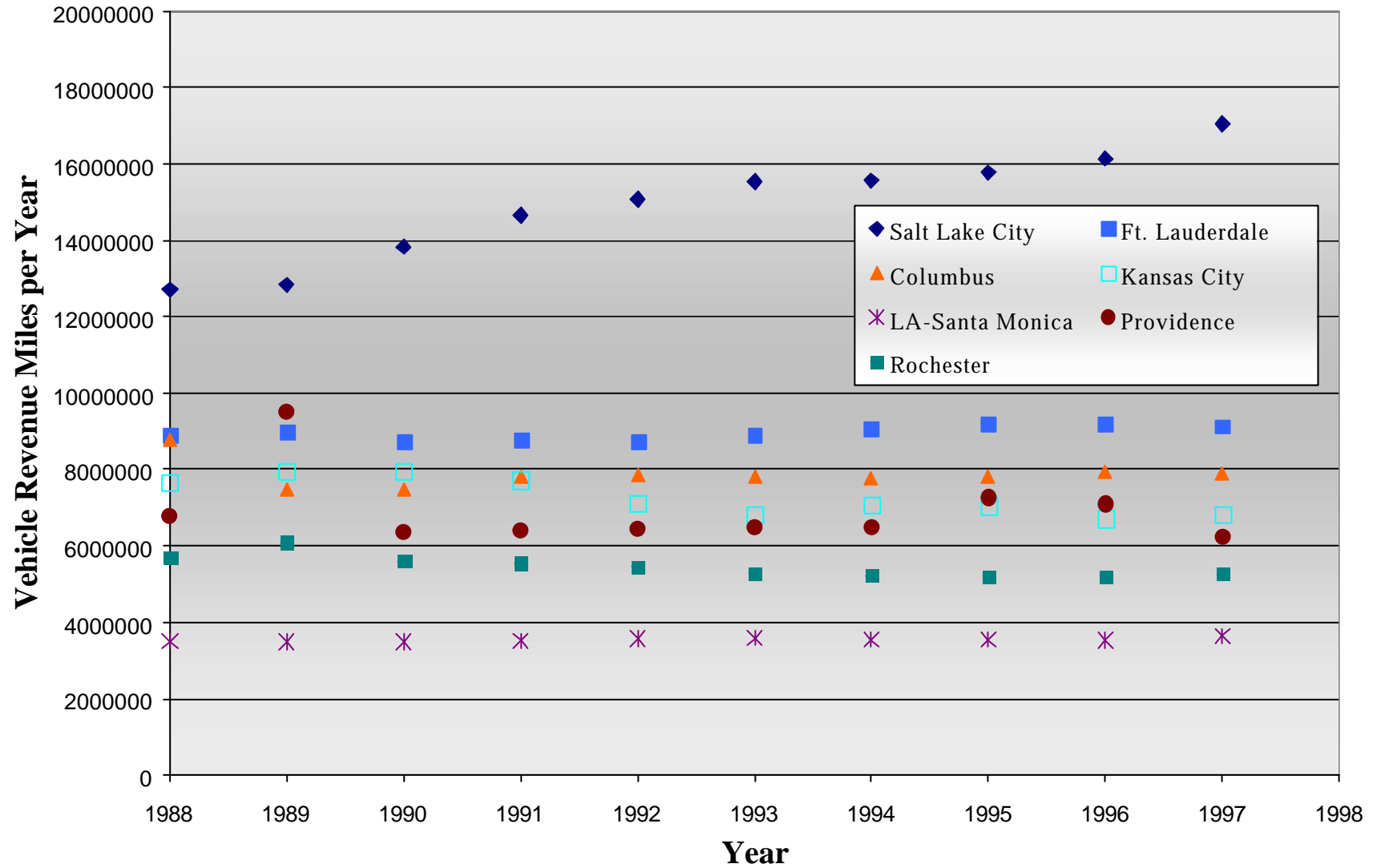


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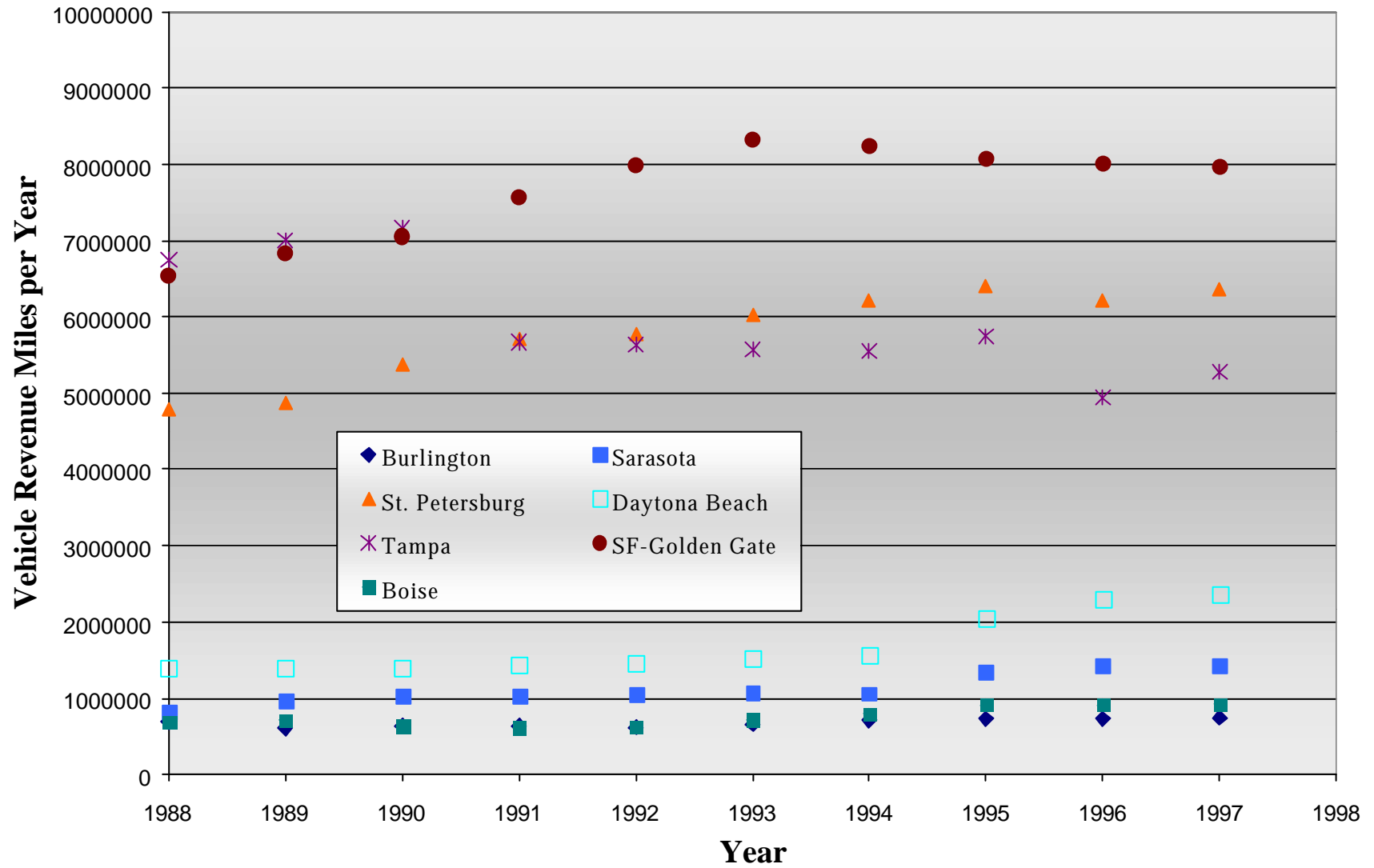


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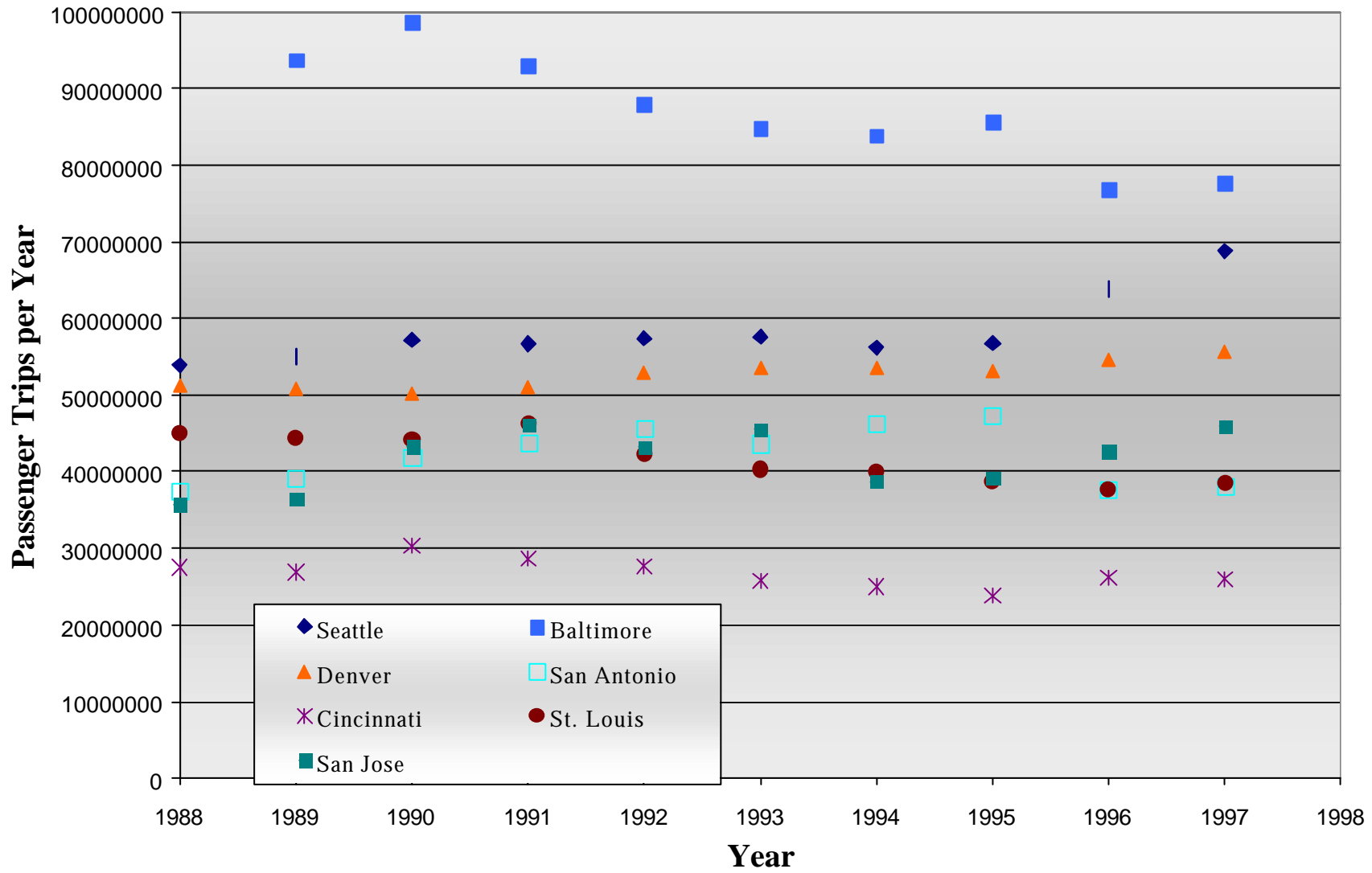
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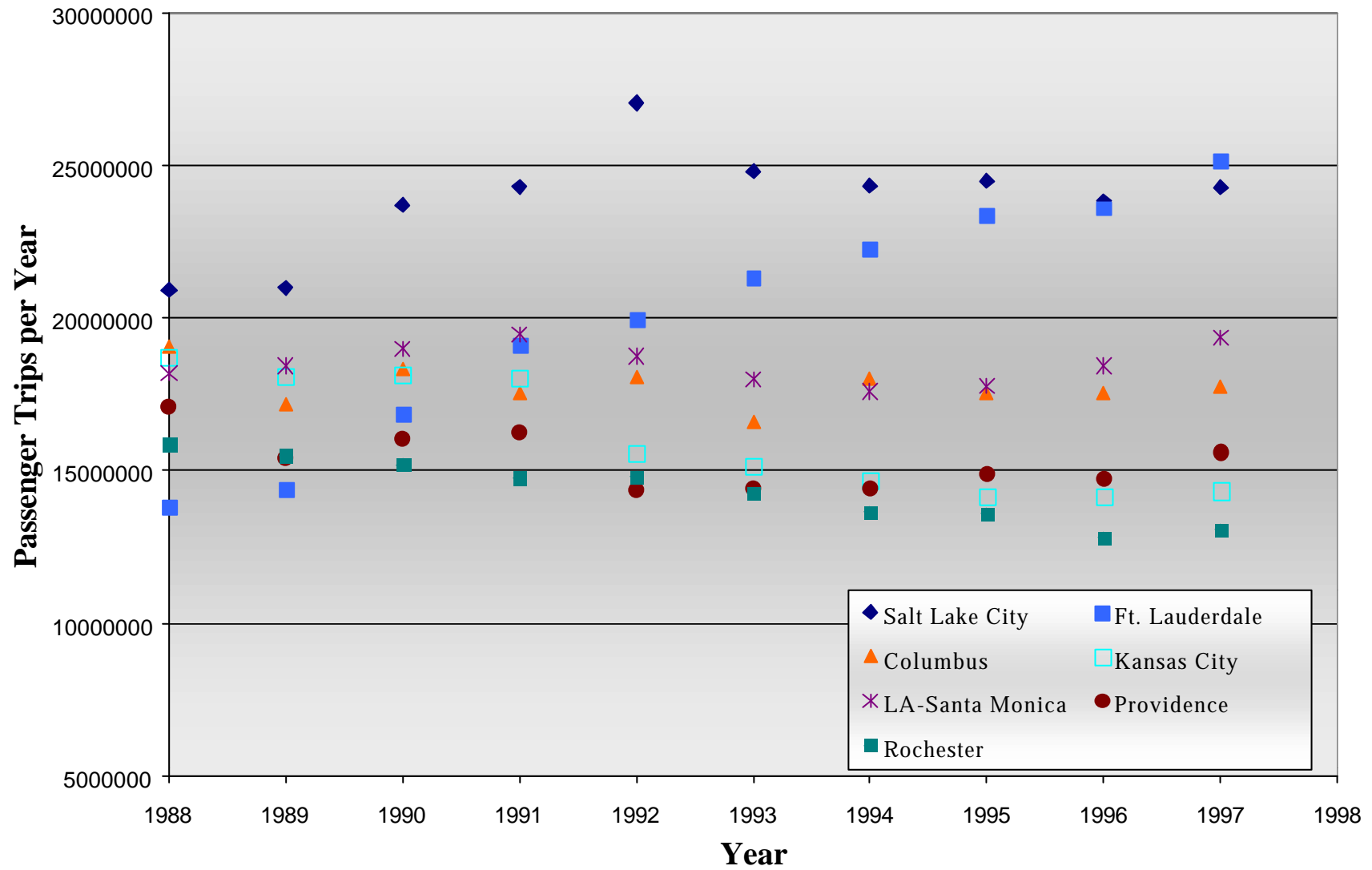


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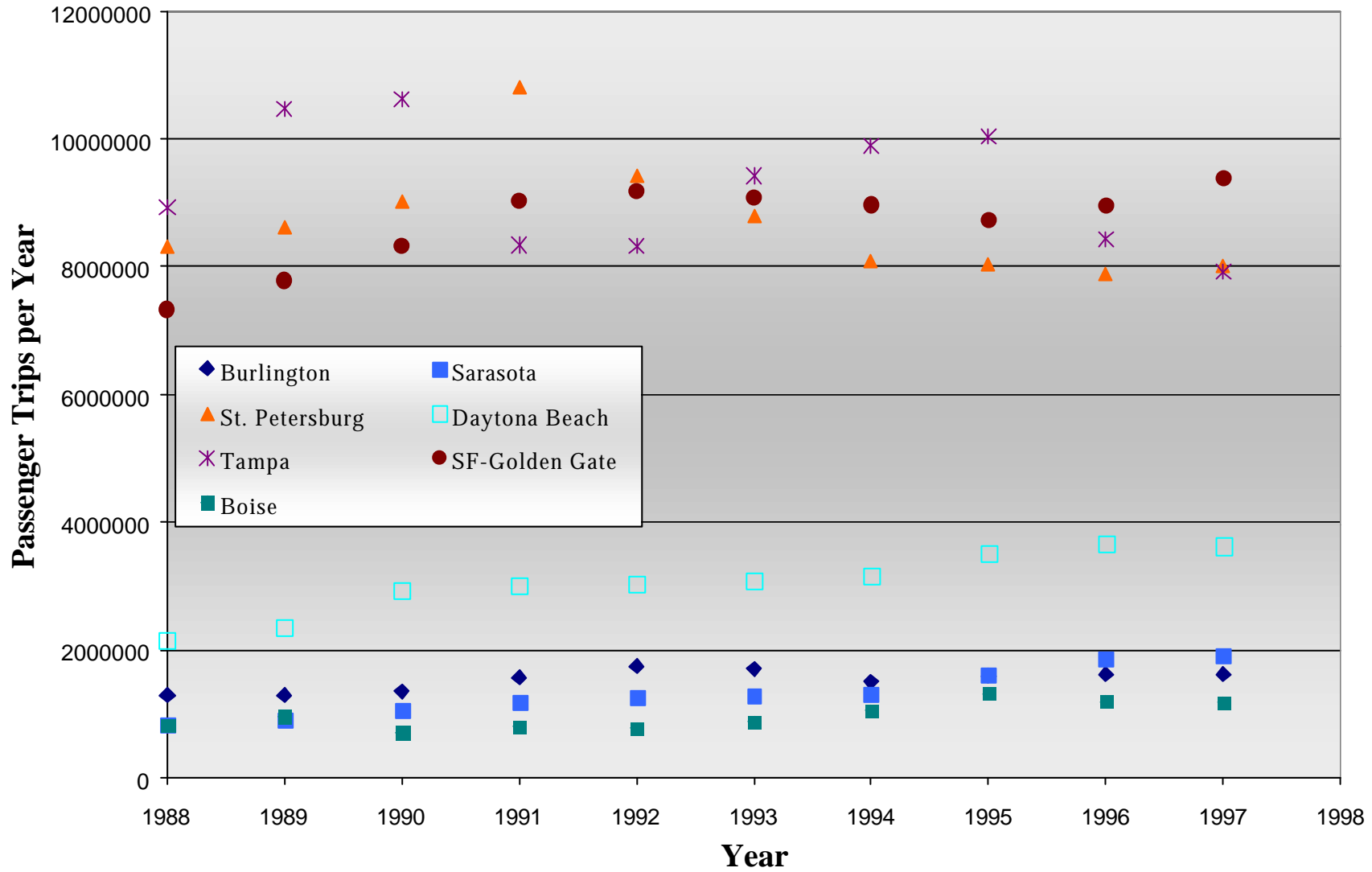


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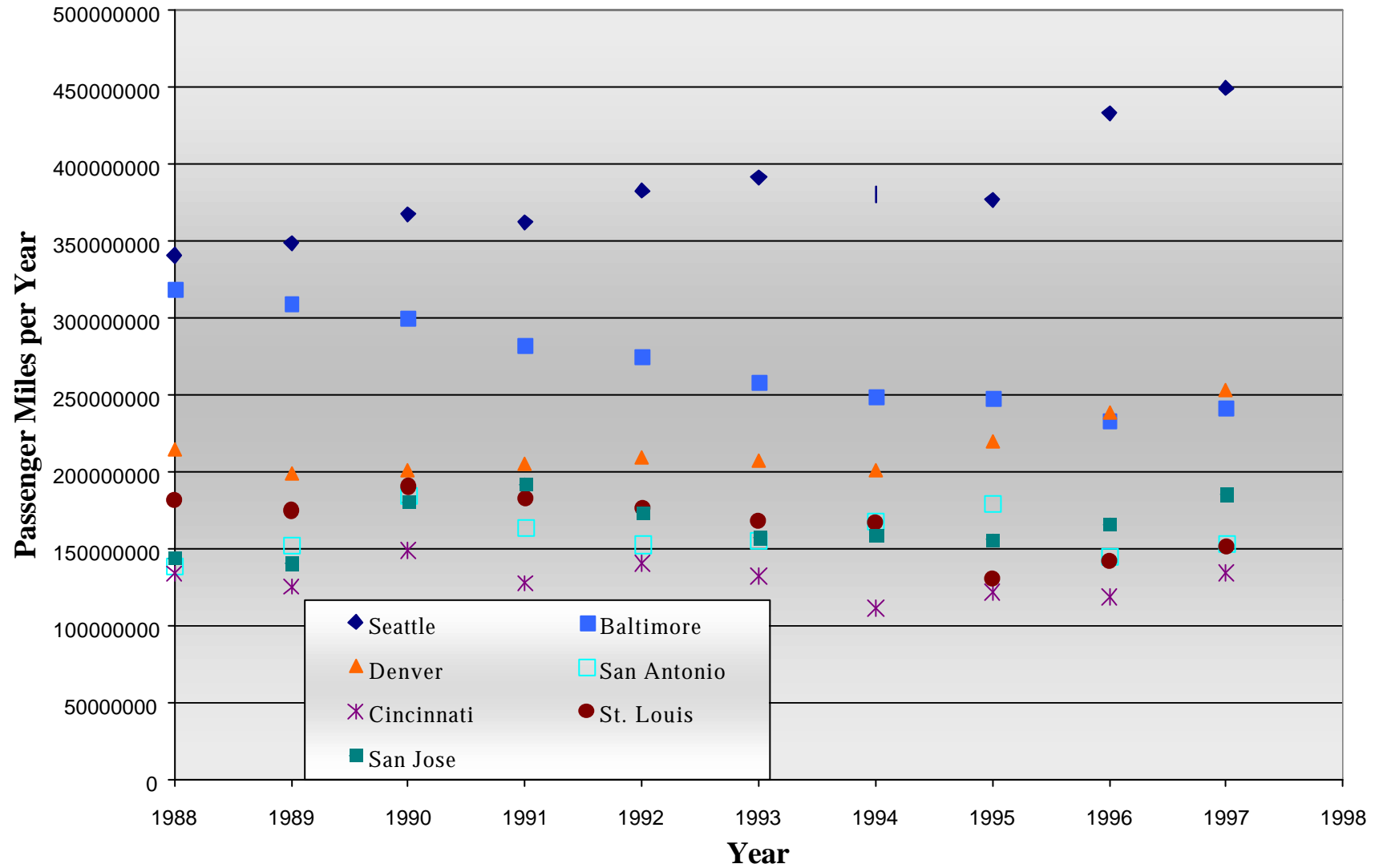
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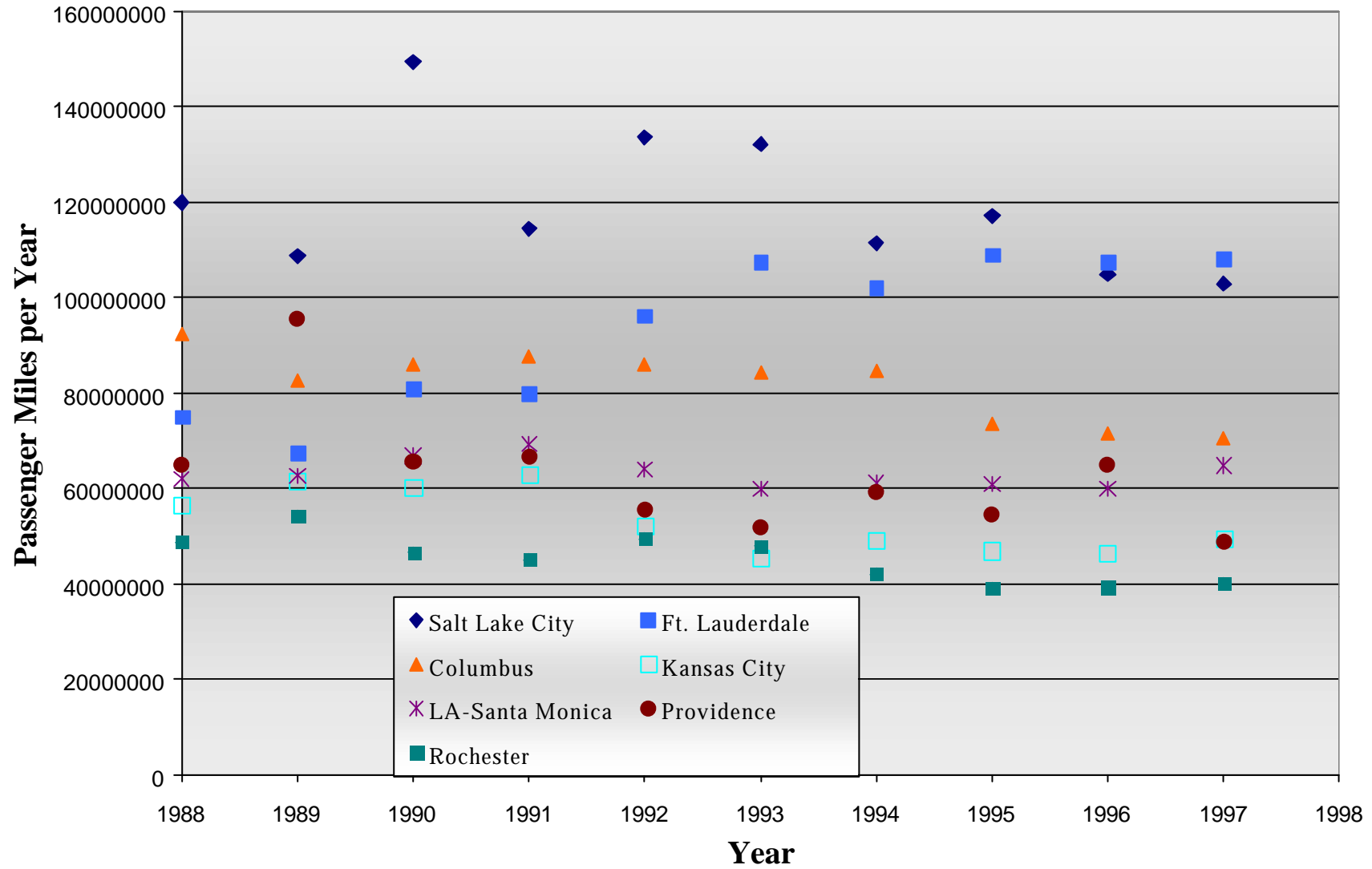
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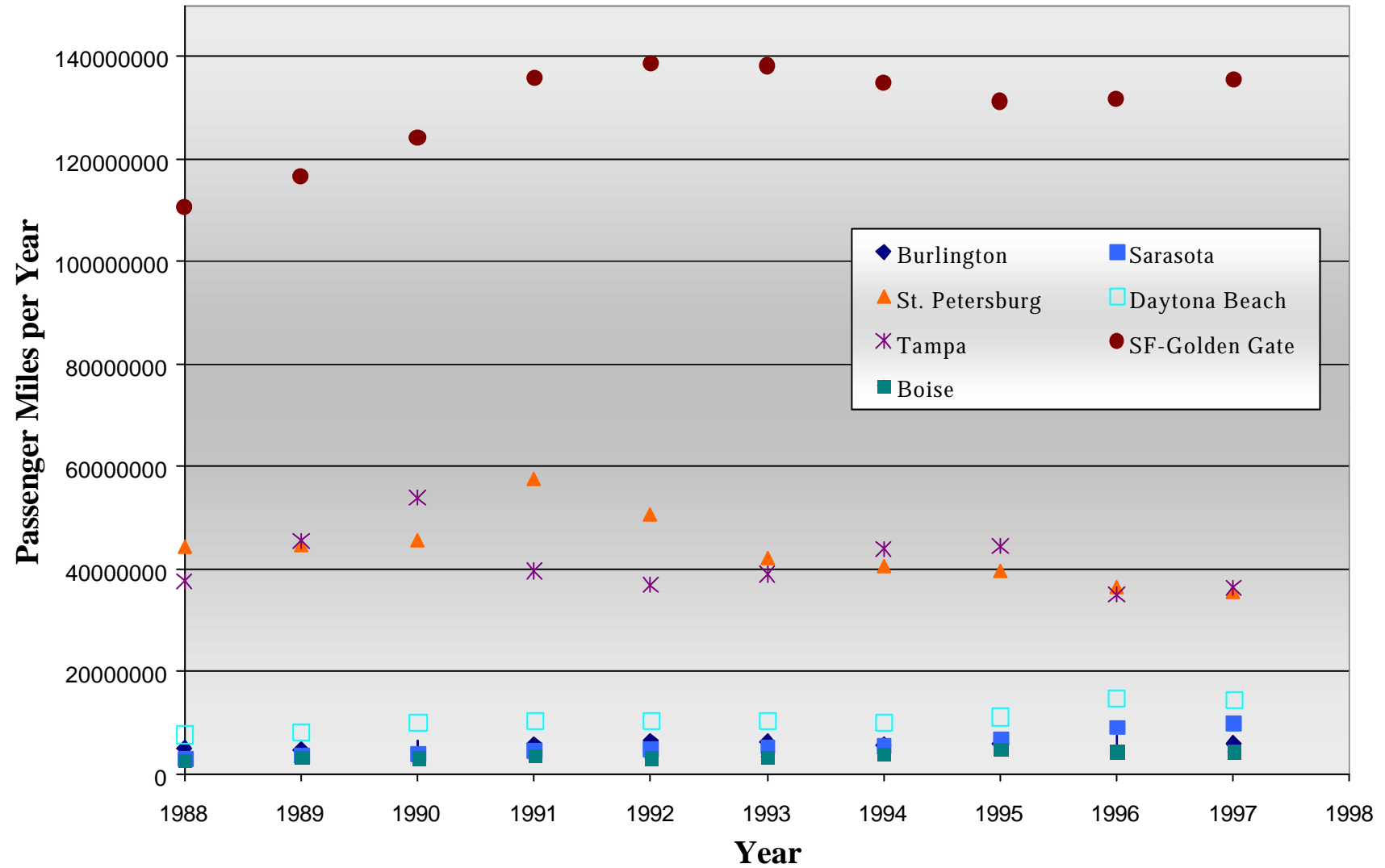




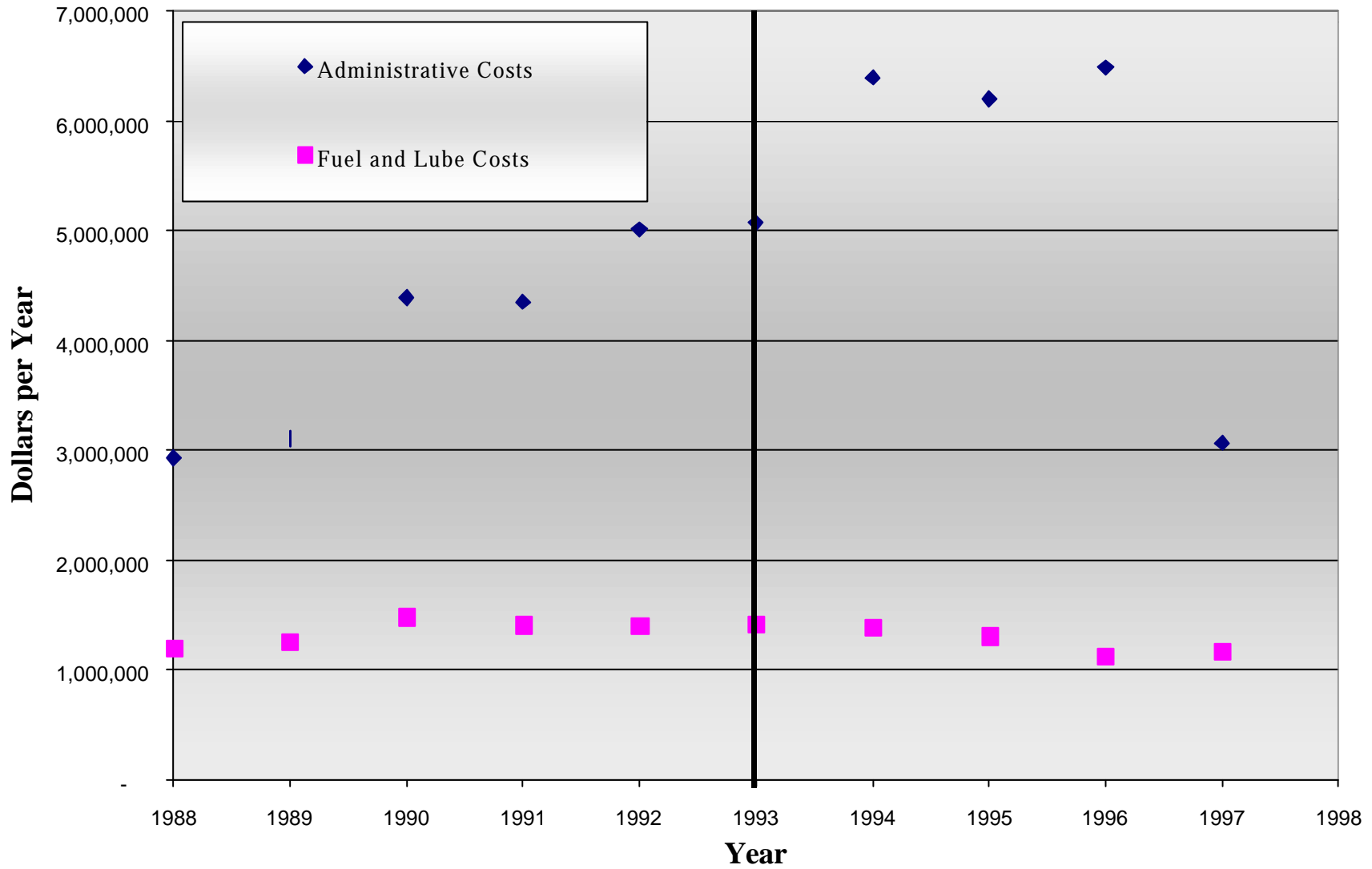
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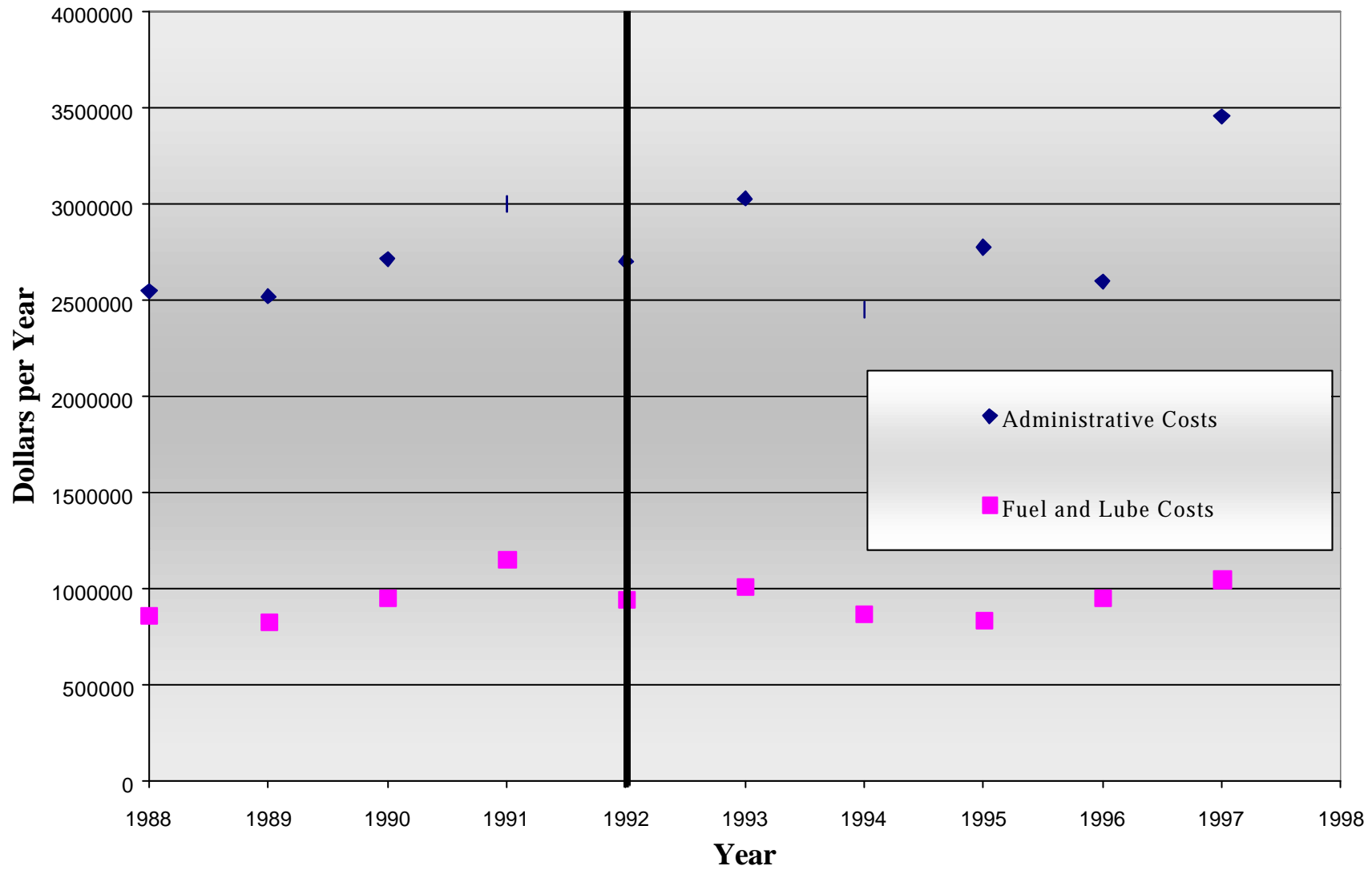


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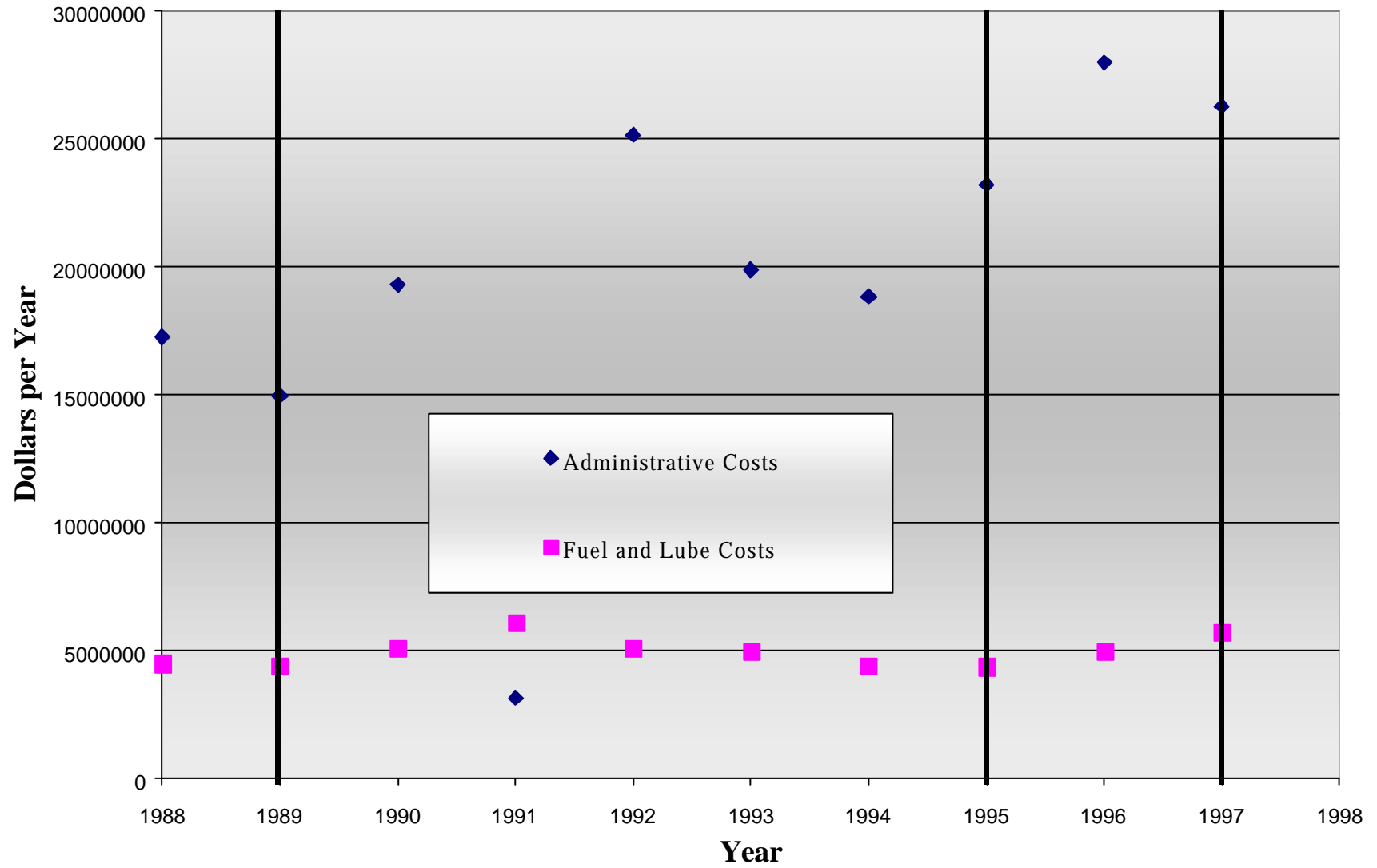


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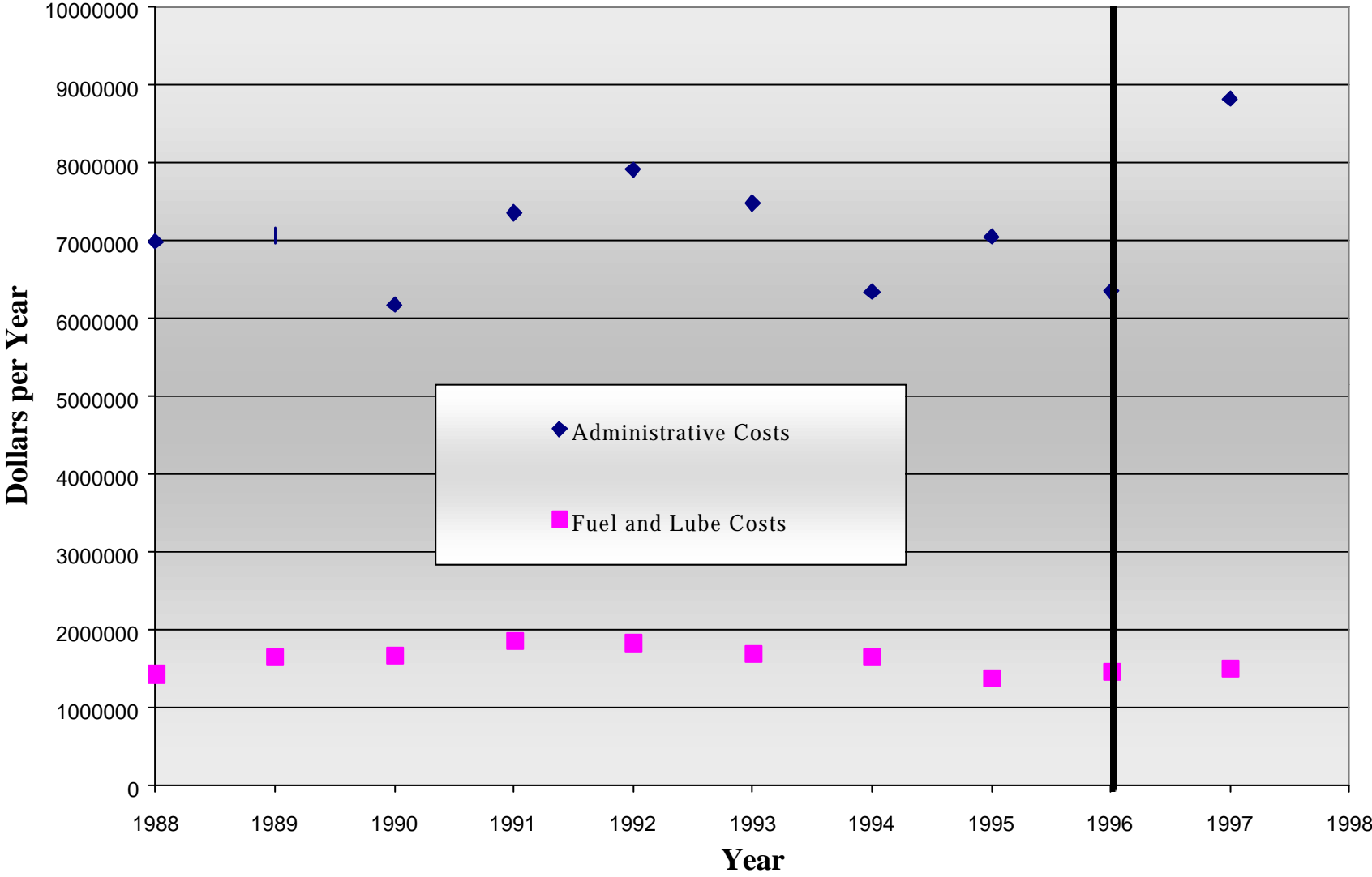
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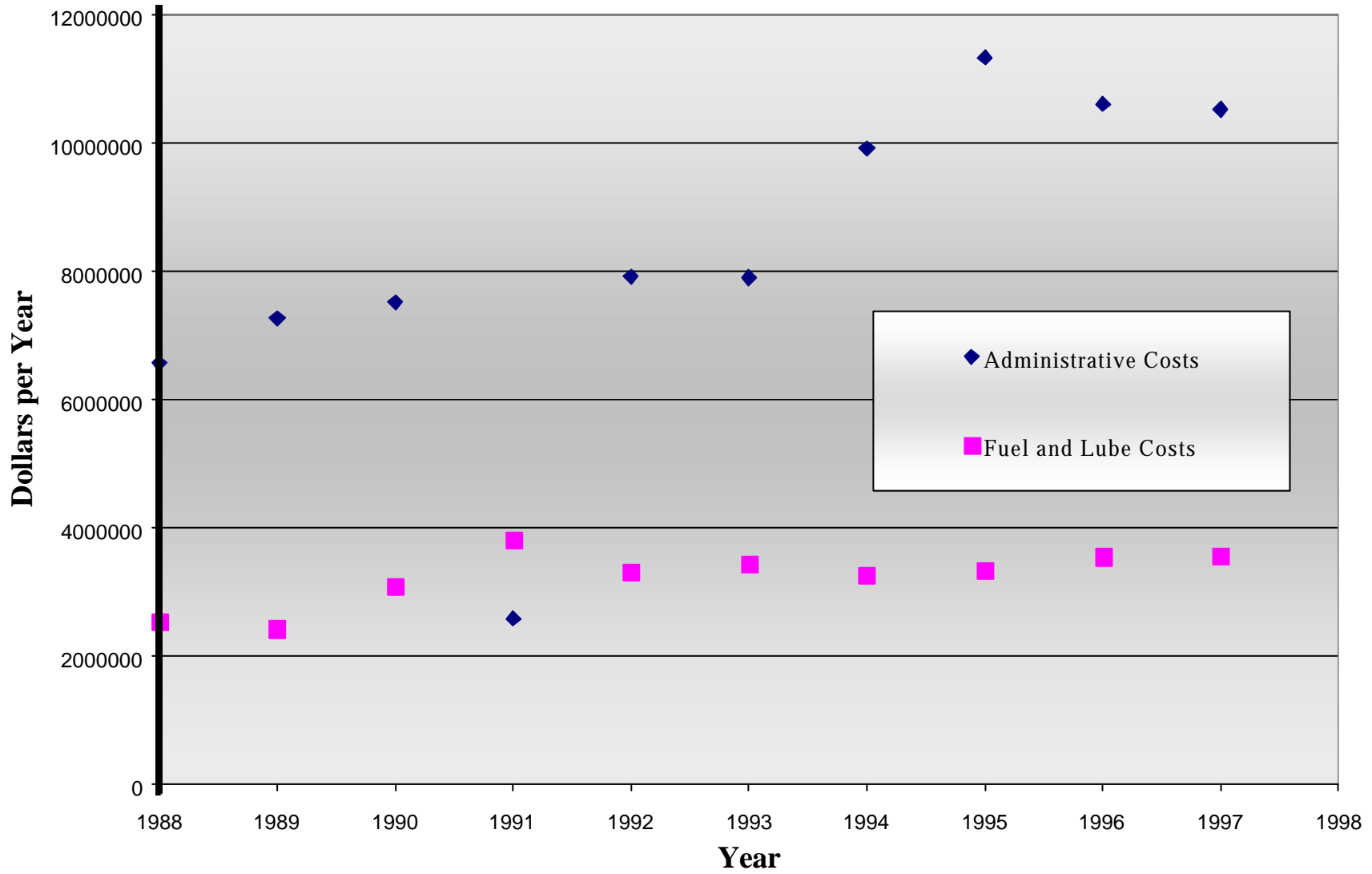
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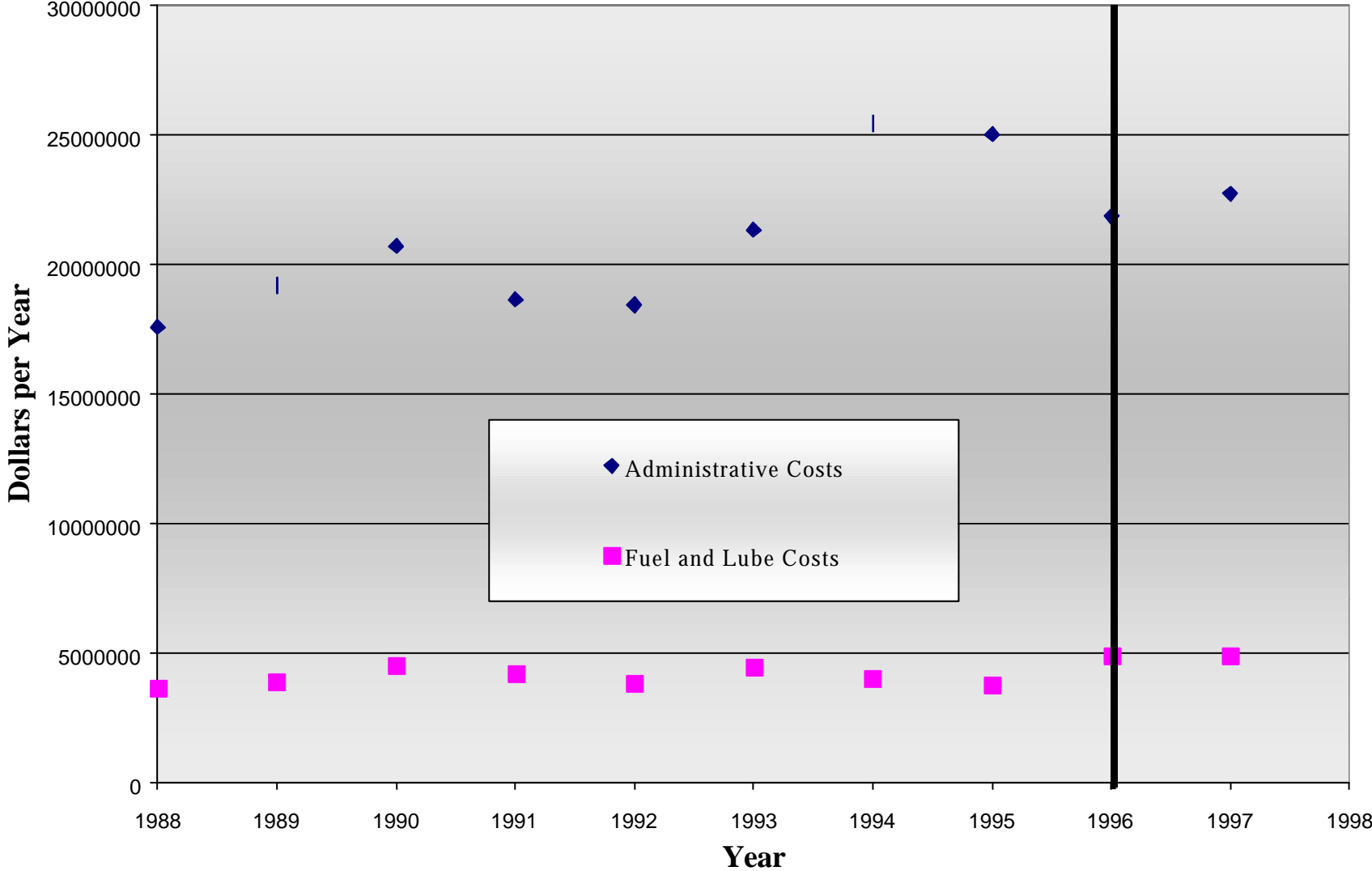
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